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The report contains articles concerning the selection and training of cosmonauts; evaluation and analysis of accumulated data to facilitate the on-going transition from orbital to interplanetary flights; research aimed at guaranteeing safety on long flights and reliability of the human component of the "man-spaceship" system; space psychology and physiology; environmental problems and control (spacecraft habitability, effects of radiation and weightlessness, etc.) and telemetry.

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QUESTION OF REDISTRIBUTION OF BLOOD IN ORTHOSTATIC POSITION

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 15, No 6, Nov-Dec 81 (manuscript received 21 Jan 81) pp 4-9

[Article by G. S. Belkaniya]

[English abstract from source] The concept of two interacting constituents involved in the redistribution of the circulating blood volume in orthostasis--redistribution along the vertical (hydrostatic) and functional (metabolic) gradients--is discussed. On this basis, the possible mechanism responsible for orthostatic circulatory intolerance following an exposure to bed rest or weightlessness is described.

[Text] At the present time, the conception of hydrostatic redistribution of circulating blood volume with the body in orthostatic position has become classical [1-8]. It can be described schematically as follows. When man changes from horizontal to vertical position, there is deposition of a certain volume (from 300 to 800 mℓ, according to different authors) of circulating blood in vessels situated below the level of the heart, as a result of an increasing gradient of hydrostatic pressure in the heart--legs direction, and this is manifested in particular in the system of capacitive vessels of the lower extremities. In addition, the volume of blood in the system of vessels between the right atrium and base of the aorta (central volume) decreases by 20% [9-11]. The diminished venous return to the heart, which is related to the hydrostatic effect, leads to a decrease [1] in minute volume of circulation (MV), even when there is a well-compensated state.

Moreover, one observes gradual shifting of fluid to the lower limbs in a man standing without motion, under the influence of hydrostatic pressure, due to increased filtration of the liquid part of blood as a result of elevation of capillary filtration pressure [2, 12-16]. Increase of the intravascular space in stretched vessels [13, 14, 16, 17] is also instrumental in the increase in extravascular fluid volume, and this also diminishes influx to the heart.

These hemodynamic changes are a manifestation of the mechanical effects of gravity, for compensation of which there are cardiovascular regulatory reactions (increased heart rate, increase in tonus of resistive and capacitive vessels). In addition, the muscular system, which provides primarily for active standing, creates certain exogenous physical conditions for hemodynamics that prevent manifestation of the hydrostatic effect--increased tonus of muscles in active orthostasis [13] prevents capacitive dilation of vessels also, while periodic muscular contractions cause

propulsion of blood over the valvular system of capacitive vessels in a central direction [1, 2]. The so-called muscle pump is the most efficient mechanism for lowering not only venous pressure [18], but capillary filtration pressure in vessels of the feet and leg in orthostatic position if blood flow in the limb is not too great and there is no deficiency of venous valves [13, 19, 20].

If the hydrostatic factor were reponsible for manifestation of orthostatic circulatory insufficiency, development of various counteracting conditions should apparently compensate for the observed hemodynamic disorders, if not completely, at least to a significant extent. In order to demonstrate the significance of the hydrostatic factors, the following main experimental procedures were used: various cuffs and elastic bandages applied to the limb; use of anti-G suit or elastic tights [or garment] and, finally, conducting orthostatic tests during immersion in water.

Although the use of inflatable cuffs on the limbs, anti-G suit or elastic garment is effective in a number of cases, it only partially prevents orthostatic tachycardia and hypotension after submersion, bed rest or exposure to weightlessness [7, 21, 24]. There was an analogous conclusion with regard to the use of a pressure suit on patients with orthostatic hypotension [25]. We should also cite data to the effect that no significant changes in arterial pressure or heart rate were demonstrable when the legs of healthy subjects were tightly bandaged while standing and then the bandage was removed [26]. A compensating effect of taping was manifested only in patients with varicose veins.

The absence of typical cardiovascular changes when conducting the orthostatic test while immersed in water has sometimes been evaluated [27] as confirmation of the significance of hydrostatics in postural reactions and attributed to the hydrostatic counteraction to accumulation of blood in the vessels of the lower extremities. At first glance, such a conclusion is quite logical. However, an important factor is overlooked--in orthostatic position during immersion there is no increase in muscle tone, which is typical for postural activity under usual conditions. And it is expressly in this part of our discussion that we wish to call attention to the factor that is usually overlooked when considering orthostatic hemodynamic changes, in spite of its obviousness. We refer to the redistribution of a significant amount of circulating blood due to increased blood flow in the muscles that are involved in holding the body in vertical position [28].

It is important to note that increased blood flow in muscles is observed not only while standing [13, 29], but during passive change to vertical position. Although blood flow increased less in muscles than it decreased in the skin, liver and spleen of dogs during the passive orthostatic test [30], the volume of the muscular "organ" was greater and for this reason redistribution of circulating blood over the entire muscular mass was significant. According to existing information [31], even a slight increase in blood flow in muscles during exercise (since skeletal muscles constitute almost 50% of body mass) plays an important part in reflex regulation of systemic arterial pressure.

The more marked changes in hemodynamics while standing [32-34] than in passive orthostatic position can be attributed to the active state of postural tonic muscles, which leads to an increase in muscular blood flow. Indeed, in both standing and passive orthostatic position, the hydrostatic factor is about the same, so that the only additional hemodynamic factor requiring regulator correction could only be redistribution of circulating blood volume to the vascular

system of muscles. There could be the following objection: with the body in passive position there is a decrease in efficiency of extravascular compensation factors, such as function of the muscle pump, suction effect of widening of the chest, etc. However, in such a case, expressly in passive orthostatic position there should be greater change in parameters characterizing systolic volume of the heart. In fact, however, the opposite occurs: stroke volume of the heart decreases more significantly when standing than in passive orthostatic position [32]. Moreover, the duration of the period of ejection of blood, which is directly related to systolic volume [35, 36], decreases much more (by 70.5%) than in passive orthostatic position (by 39%). It should be stressed that the reduction of the period of blood ejection is not related to shortening of the cardiac cycle, since the increase in heart rate constituted only 18.7% when standing and 12.6% in passive orthostatic position [34].

Thus, it has been established that, on the one hand, increase in tonus and periodic contractions of muscles (primarily of the lower limbs) in orthostasis causes venous efflux and, on the other hand, functional increase in capacity of muscular vessels enhances manifestation of the hydrostatic factor. This is indicated, in particular, by observations of athletes who showed an abrupt and drastic drop of systolic blood pressure, to the extent of loss of consciousness, after running if they stopped suddenly and stood in place [37]. This state is related more to considerable redistribution of blood in muscles and increase in capacity of vessels of the lower limbs, against the background of which there is drastic intensification of the effect of the hydrostatic burden in orthostasis, than to dilatation of abdominal vessels, as interpreted in these cases. The opinion is held [2] that participation of the entire muscular mass in intensive physical exercise is the cause of the greatest load on the cardiovascular system.

Evidently, enhancement of manifestation of the hydrostatic factor in patients with varicose veins, as compared to healthy subjects [38], is related not only to attenuation of tonic properties of venous vessels, but initial increased blood volume in the capacitive system of vessels of the lower extremities.

If we consider that there is a 12-15-fold increase in local blood flow in a functioning muscle [39], the hypothetical volume of circulating blood in muscles could reach an enormous level (10-12 ℓ) during muscular exertion with a total weight of skeletal muscles of 28 kg (in a nominal man weighing 70 kg) and initial (resting) blood volume in muscles of 30 mℓ/kg [40] (which constitutes 840 mℓ for the entire mass of muscles). This is more than double the real total circulating blood volume in the human body (5.5 ℓ). According to available data [2], regional blood flow in skeletal muscles with maximum vasodilatation and pressure gradient of about 100 mm Hg could be even more significant--20,000 mℓ/min--which is several times more than blood flow in other vascular regions of the body. In other words, the muscles are an enormous reservoir for circulating blood volume and, no doubt, when it is functionally filled during postural-tonic muscular tension, this is one of the appreciable factors of perturbation of central hemodynamics.

The redistribution of circulating blood volume in orthostatic position is active and, on the basis of conceptions of regional and systemic vasomotor reflexes [41, 42] and autoregulation of myogenic tonus [2], it can be schematically described as follows (see diagram). During postural-tonic tension of muscles there is vascular dilatation as a result of change in metabolic and histochemical conditions. Vascular dilatation alone is not enough for a working muscle; there must also be an additional volume of blood. For expressly this reason, regulation of circulation cannot

be limited to the function of one organ in the intact organism. The local metabolic control circuit is not sufficient for adequate implementation of muscular blood flow and a second, reflex circuit for regulating circulation is turned on: excretion of metabolites--stimulation of tissular receptors--excitation of tissular receptors--excitation of vasomotor center--compensatory vasoconstriction--functional hyperemia [41]. Compensatory constriction also occurs in another way, over the arc of conjugate reflexes upon stimulation of the main mechanireceptor reflexogenic zones of the cardiovascular system, vestibular receptors, as well as on the basis of motovisceral regulation [43]. In this regard, some rather interesting data were recently obtained [44]. Studies of systemic circulatory reactions to orthostatic factors against the background of curarization revealed marked decrease in orthostatic stability, as was observed also in other, earlier studies [43]. This effect could be evaluated only as the result of weaker functioning of the muscle pump, if we do not take into consideration the total exclusion of constrictive reactions of resistive vessels with administration of curare, which was demonstrated by L. I. Osadchiy [44]. At the same time, electric stimulation of the tibial nerve continued to elicit systemc vasoconstriction even with relaxed muscles. The latter was clearly demonstrated in intact animals [43], and attributed to the influence of muscular receptors on resistive vessels. As a result of interaction between autoregulatory and systemic mechanisms, there is a decrease in blood flow in other organs--skin, spleen and liver [30], kidneys [45-48] and lungs [9, 38, 49]. The additional volume of circulating blood thus mobilized is redistributed in the vascular system of muscles.

The "vasomotor autonomy" phenomenon [41], or "escape" [30] of dilated muscular vessels from central constrictor nerve infuences is important to regulation. This phenomenon is based, according to modern conceptions, on the distinctions of biophysical properties of vessels (diminished radius of lumen and rigidity of the wall).

On the basis of the developed conception of redistribution of blood with the body in vertical position, it should be noted that the lower body negative pressure test used extensively at the present time in space medicine [7, 24], which does simulate hydrostatic redistribution of blood to some extent, does not reflect the actual redistribution of circulating blood volume that occurs during standing.

In view of the foregoing, one should bear in mind two interacting components of redistribution of blood in orthostatic position: redistribution of blood over the vertical (hydrostatic) pressure gradient in the vascular bed below the level of the heart and redistribution in the vascular bed of muscles, particularly antigravity muscles, over the "functional" or "metabolic" gradient.

It is expressly the synergistic action of these two factors that determines the direction of compensatory orthostatic reactions and is the basis of the observed hemodynamic disorders. It is also important to note that, while hydrostatic pressure is constant throughout the period of a test, blood flow in muscles depends on the degree of tension of antigravity muscles that are active in orthostasis. It can be assumed that the intensity of the hydrostatic factor will also depend on muscular blood flow. Moreover, the muscle pump, which we mentioned above, ceases to be an efficient mechanism for lowering capillary filtration pressure in the vessels of the lower extremities with increasing blood flow in muscles in orthostatic position.

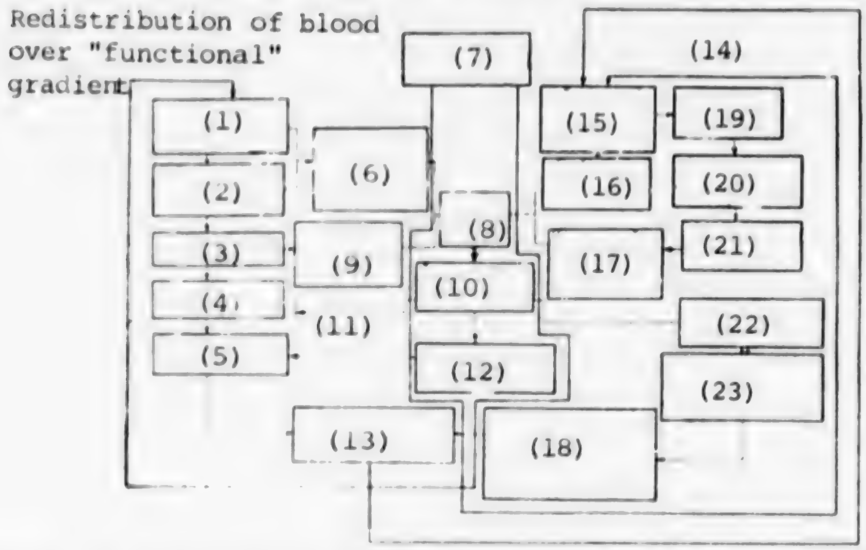

Diagram of redistribution of circulating blood volume over "hydrostatic" and "functional"gradient in orthostatic position

Key:

1) increased weight load on skeleton and muscles
2) increased tonus of antigravity muscles
3) increased metabolism
4) dilatation of muscular vessels
5) increased blood flow in muscles
6) increased functional activity of proprioceptors
7) mechanical effects of gravity
8) vasomotor center
9) increased activity of tissular receptors
10) systemic compensatory vasoconstriction
11) escape phenomenon
12) increased prefusion pressure
13) increased circulating blood volume in muscles
14) redistribution of blood over hydrostatic gradient
15) elevation of venous pressure in leg vessels
16) stimulation of venous mechanoreceptors
17) change in excitability of central baroreceptors
18) decreased circulating blood volume in the liver, kidneys, lungs, spleen, skin
19) decreased venous return
20) decreased systolic volume
21) decreased perfusion pressure
22) constriction of internal organ vessels
23) decreased blood flow in liver, spleen, kidneys, lungs, skin

There is validity to the hypothesis that the decrease in orthostatic stability after use of factors that are associated with decrease in functional capability of the muscular system (for example, after hypokinesia, weightlessness) is related to a greater hemodynamic demand of postural-tonic muscles that function with more tension in orthostasis. This could be related to both a decrease in muscle mass and decrease in force and static endurance of muscles, particularly those of the lower limbs (antigravity), which is associated with less economical function

and greater oxygen "cost" of the load [50], as well as difficulty in maintaining a vertical position [51].

The results of studies that demonstrated that energy expenditure by individuals with poor orthostatic stability is several times greater than in subjects with good orthostatic stability [52] serve as some confirmation of the foregoing.

Of course, it should be borne in mind that, in the presence of atrophic processes, weakening of "retaining force" of fatty, muscular and support tissues leads to greater mobility of extracellular fluid and causes onset of orthostatic edema, even without complicated disorders regulating the volume of mechanisms [53-55].

There are two directions to the compensatory reaction of the circulatory system in orthostasis. On the one hand, there is compensation of blood deposited over the vertical (hydrostatic) pressure gradient in the venous system below the level of the heart. On the other hand, an active orthostatic position, which is associated with increased overall metabolism, increase in energy requirements and energy expenditure by various systems of the body (primarily antigravity muscles), requires appropriate back-up on the part of hemocirculation, which is associated with additional redistribution of blood via the "functional" or "metabolic" gradient. It thus becomes clear that, in addition to its autonomous regulatory mechanism, the cardiovascular system must have two-way connections with other systems of the body, and this occurs within the framework of a common mechanism of systemic regulation of the organism [56] for the gravity factor.

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WAYS AND MEANS OF MAINTAINING HEAT BALANCE IN PILOTS AND COSMONAUTS

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 15, No 6, Nov-Dec 81 (manuscript received 30 Mar 81) pp 9-15

[Article by A. S. Barer]

[English abstract from source] Different principles used in systems ensuring thermal balance of pilots and cosmonauts are discussed. Physiological and hygienic characteristics of the passive thermal insulation, ventilation systems and liquid cooling (heating) suits are presented. A classification of the means and methods is proposed.

[Text] There are several basically different but, at the same time, mutually supplementary artificial means of preserving man's heat balance.

All of the known methods aimed at solving this problem can be divided into so-called passive and active ones.

Arbitrarily, the ways and means that do not provide for dynamic regulation of the main parameters are classified as passive. Most often, this refers simply to the choice of a clothing package (including special gear) on the basis of such parameters as thermal resistance, reflectivity, vapor conductivity, fireproof features, etc. The active methods are the ways and means that provide for such regulation.

We could mention liquid cooling, heating or ventilation of insulating gear and space suits as examples of active methods of maintaining temperature homeostasis. In both cases, it is possible to regulate the outlay and temperature of the coolant (liquid, gas).

All systems of artificially maintaining temperature homeostasis of the body can also be divided into two main categories according to breadth of capabilities. The first refers to systems that maintain heat balance over a wide range of exogenous and endogenous loads. Such systems are called upon to prevent both overheating and overcooling of the body. The second category refers to systems that perform only one of these tasks.

Ventilation and liquid-using systems (together with units for conditioning coolant) are the most vivid representatives of systems referable to the first category. The electric heating system, as well as the system for vacuum evaporation of liquid (perspiration) can be referred to the second category.

1. Passive heat-shielding properties of gear. The choice of heat-resistance for different types of human gear is determined by a set of requirements related to the conditions of its use and structural distinctions.

For aviation gear, in particular for altitude compensating suits or marine rescue suits, which usually have a ventilation system of heat regulation, the choice of heat-shielding properties (thermal resistance) of the package of fabrics is determined primarily by the distinctions of instances when the ventilation system is not operational. They include the stages of waiting to take off, abandonment of an aircraft in case of emergency by means of ejection and subsequent descent with a parachute, possibility of emergency landing (on the ground or water) in arctic regions, etc.

The estimated time that a man spends under extreme thermal conditions is an important factor.

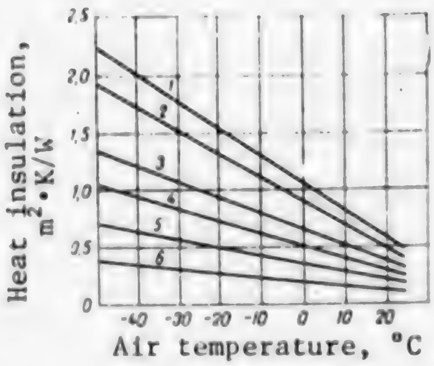

Figure 1.
Required heat shielding as a function of intensity of work and air temperature [1]
1) sleep
2) calm
3-6) heat production of 120, 170, 240 and 490 W, respectively

Figure 1 illustrates the needed heat insulation for man to maintain a close to normal thermal state for a long period of time [1]. Such cumbersome gear would have to be developed to meet these requirements that it would unquestionably be incompatible with a number of work processes, for example, flying. For this reason, to estimate passive protection, one proceeds from a compromise, which takes into consideration the probability of an emergency situation and the limited time that man is exposed to it.

As for the pilot and his special gear, the so-called thermal garment that is part of the altitude suit or marine rescue suit plays the main part in passive heat insulation. Such a garment is made of wool knit fabric and weighs about 1.8 kgf [sic]. Its heat resistance is 0.13 m^2 K/W, i.e., about 0.84 clo. Overall thermal resistance of the gear package, including the altitude suit, of course consists of the sum of thermal resistances of all its layers, with consideration of the air layers between them, and constitutes about 0.22-0.34 m^2 °K/W (1.4-2.2 clo).

The conditions under which a man wearing an altitude suit [or space suit] is exposed to open space or on the surface of the moon advance some additional requirements as to passive heat insulation.

In view of the high intensity of exogenous thermal flux, as well as the possibility of change in its direction, depending on whether the cosmonaut is in the shade or under the direct rays of the sun, one generally reduces to a minimum heat transfer between the cosmonaut and environment by means of special structural elements in the suit, while the life-support systems in the suit divert endogenous heat from his body

The cosmonaut is shielded from ambient heat in two main ways: by selecting fabric for the outer layer of the suit having optimum optical characteristics and adding shield-vacuum insulation (SVI) to the construction of the suit.

The physical principle on which the SVI operates is essentially the same as for a Dewar flask. It consists of several thin film shields, between which vacuum is retained due to perforations in the film. In order to obtain high reflectivity of the shields a thin layer (50-100 nm) of metal (aluminum, gold, germanium) is applied to them.

2. Active artificial maintenance of heat balance in the body under extreme conditions. Among the methods used for active maintenance of heat balance under extreme conditions, ventilation systems are the most popular. Heat balance is maintained by the ventilation system by means of convection and evaporation of perspiration. There is retention, to some extent, of radiation and conductive heat transfer between the surface of the body and inside surface of clothing.

In the case of protection against overheating, the temperature of ventilated gas must be lower than the mean weighted skin temperature in order to provide for convective removal of heat from the body. If there is a danger of overcooling, the gas temperature at the input in the gear must be higher than skin temperature to cause convective influx of heat in the body.

There is one more, equally important task that the ventilation system of insulating gear, including aviation and space suits, must perform--it must supply oxygen to the body.

In the simplest case, the ventilation system of insulating gear can be constructed in the form of a system of perforated tubes 6-8 mm in diameter. For a space suit, these tubes are secured to the inside surface of the heat-insulating garment. All of the tubes are connected by means of a collector into one main line over which air from the conditioning system passes into the space under the clothing.

Thermal estimation of the ventilation system consists of combined solution of equations of heat balance of man in his gear. In general, the equation of thermal balance for an established mode of the man-ventilated gear system is described in the following manner:

$$H + Q_{rt} + Q_{pas} + C + E = 0 \quad (1)$$

where H is the body's heat production, Q_{rt} is heat transfer in the respiratory tract, Q_{pas} is passive heat transfer between man and gear, C is convective heat emission from the surface of the body and E is heat emission by evaporation of perspiration.

Of course, Q_{rt}, C and Q_{pas} can have both positive and negative values, depending on ambient conditions and choice of gas temperature at the input of the ventilated system.

Let us consider the main patterns of convective heat transfer in ventilation gear. Making certain assumptions, we can consider that the intensity of convective heat exchange between the integument and flow of gas can be described by the following expression:

$$C = \dot{m}\, C_p(\overline{T}_s - \dot{T}_g) \times \left[1 - e^{-\frac{h_{conv} A_{conv}}{\dot{m} C_p}}\right] \tag{2}$$

where $\dot{m}$ is mass velocity of gas flow, C_p is specific heat of gas at constant pressure, $\overline{T}_s$ is mean weighted skin temperature, T_g is gas temperature at input of the system, A_{conv} is effective surface of convective heat transfer, h_{conv} is coefficient of heat transfer between the skin and gas flow.

We see that with infinitely high values for the coefficient or area of heat transfer, i.e., under "ideal" conditions, the intensity of heat transfer has a maximum value of $C = C_{pot}$, where C_{pot} is "potential" heating efficiency [heat value] of the system:

$$C_{pot} = \dot{m}\, C_p(\overline{T}_s - T_g) \tag{3}$$

For a real garment, it is correct to consider:

$$C = C_{pot} \cdot \varepsilon_{conv};/\varepsilon_{conv}/ \leqslant 1 \tag{4}$$

where ε_{conv} is heat efficiency of the system:

$$\varepsilon_{conv} = \frac{C}{C_{pot}} = 1 - e^{-\frac{h_{conv} A_{conv}}{\dot{m} C_p}} \tag{5}$$

Hence, other conditions being equal, the efficiency of the system can be improved both by increasing the surface of heat transfer, i.e., ventilated area of body surface, and by increasing the coefficient of heat transfer, i.e., uniformity of distribution of the flow of ventilating gas.

Because of the constructive restrictions, the efficiency of existing ventilation systems does not exceed 0.6-0.8 for heat transfer; thus, the actual convective heat transfer does not exceed 60-80% of potential heating efficiency of the system.

On the whole, the share of convective heat transfer in overall heat transfer in ventilated systems is relatively small, and it is substantially exceeded by the heat loss due to evaporation of perspiration.

Under normal conditions, heat loss by evaporation of sweat constitutes about one-fourth of the body's total heat emission, and it increases drastically when there is an increase in heat production or elevation of external temperature.

The rate of heat emission by evaporation of perspiration E can be determined with the following equation:

$$E = \lambda \eta \mu \tag{6}$$

where λ is latent heat of evaporation of perspiration—2300 kJ/kg, μ is overall rate of perspiration, kg/s, η is efficiency of perspiration, i.e., share of sweat evaporated in the flow of gas.

Since the body provides for an optimum rate of perspiration, the ventilation garment creates the conditions for evaporation of this amount of sweat, i.e., conditions under which the efficiency of perspiration comes close to one. The efficiency of perspiration can be improved by lowering humidity of the gas at the input of the system, as well as by improving the distribution of gas flow over the body surface with due consideration of topography of perspiration.

One must also bear in mind some physiological restrictions on use of ventilation systems. First of all, one must consider that the overall level of dehydration of the body must not exceed 1.5-2% of body weight. Extreme gas temperatures at the input of the system are also important. Thus, when temperature rises to 45-47°C and velocity of gas in the space under the garmet is of the order of 10 m/s, there may be painful sensations.

There are also serious technical restrictions on the use of ventilation systems. One of them is the inadequate overall efficiency against the background of high, but very realistic endogenous or exogenous heat loads. For example, the ventilation system in the space suits of American astronauts who flew aboard a spacecraft of the Gemini type could not handle evaporation of sweat and diversion of heat, and thus limited the possible volume of extravehicular work. As for the capability of such systems, there must be a gas flow of 1000-2000 ℓ/min (at barometric pressure of 0.25 ati [atm(gage)]) to remove heat and sweat vapor from a cosmonaut performing physical work, which requires 5 times more energy than at rest. A fan with an electric motor of several hundred watts can provide for circulation of such a flow of gas. For this, one would need a powerful and heavy source of power, which is virtually impossible in a modern space suit [2].

The liquid-cooled (heated) garment--LCG--has considerable advantages. The method of removing (delivering) heat directly from the surface of the human body by means of a liquid that plays the role of heat carrier is highly effective in handling both endogenous and exogenous thermal loads. Such a garment was used for the first time during the lunar mission on the Apollo program, and the first work on it in 1962 was related to the problem of providing for temperature homeostasis in pilots expecting to take off in an aircraft heated by solar rays [2, 3].

The LCG is a one-piece garment [jump suit] with a system of polymer tubes installed on it, through which water circulates [4]. The overall length of tubing depends on the required heating efficiency of the garment and its structural distinctions (full-size garmet, cooling vest, trousers, separate panels, cap, etc.). The maximum length of tubing for a full jump suit is 100-120 m. As a rule, water circulates in the tubing of the LCG at a constant rate of 1.5-3.0 ℓ/min. Water temperature at the input into the garment is usually the main parameter that is regulated, and it depends on flow of water through the heat exchanger.

From the physiological point of view, the task of optimum distribution of LCG tubes over the human body is a rather serious one. There can be two basic ways of performing this task. In one variant, the amount of cooling tubes should be proportional to mass or area of cooled (heated) body region. The largest number of tubes will be in the region of the trunk, thighs and shoulder girdle. Thus, in this case, maximum heat transfer occurs at the sites of the main masses of skeletal muscles of the main source of metabolic heat.

At the same time, it is known that a number of regions of the human body play a dominant role in heat exchange between the body and environment. They include the head, interscapular region, legs, feet, forearms and hands. In the second variant, the location of the tubing over the human body there is consideration of expressly this circumstance [5]. In the opinion of the American specialist, P. Webb [2], the LCG tubing should be arranged in the following manner: 50% on the legs, 23% on the hands, 19% on the trunk and 8% on the head and neck. The flow of coolant in the tubes should constitute 40% for the legs (including the feet), 26% for the arms (including the hands), 22% for the head and 12% for the trunk.

Marked reduction of perspiration, even when there is high heat production in the body, is an important feature of the physiological effect of the LCG. Thus, when performing moderate and heavy work (400-500 W) loss of moisture does not exceed 0.15-0.20 kg/h with the use of conductive cooling of the body by means of the LCG.

For a system of conductive liquid cooling, the equation for heat balance in the man-gear system of the following general appearance (stationary case) applies:

$$H + Q_{rt} + Q_{pas} + K + E = 0 \tag{7}$$

Let us discuss in greater detail the conductive component K that is the most specific to this system and most significant in heat transfer.

As in the case of ventilation systems, the following equation is valid:

$$K = C_p\dot{m}(T_s - T_f) \times \left(1 - e^{-\frac{h_{cond}A_{cond}}{\dot{m}C_p}}\right) \tag{8}$$

where T_f is temperature of liquid at the input of the system, A_{cond} is effective area of conductive heat transfer, h_{cond} is the coefficient of conductive heat transfer.

This equation can be rewritten in the following form:

$$K = K_{pot} \cdot \varepsilon_{cond}$$

where K is actual intensity of conductive heat exchange between body surface and LCG tubing, K_{pot} is potential heating capacity of the LCG system with an infintely large area or coefficient of heat transfer, ε_{cond} is thermal efficiency of the LCG system.

Figure 2 illustrates estimated conductive heat removal provided by the LCG as a function of temperature of heat carrier [coolant] at the input of the system and temperature difference at the ends of the systems with different values of mass velocity of flow [4].

An important advantage of liquid-using systems to maintain heat balance over ventilation systems is that they are very economical. This is particularly noticeable when heat transfer occurs at high rates. For example, in the case of heat transfer at the rate of 200 W, it was demonstrated [6] that the required power of the pump providing for the given heat transfer should, other conditions being

equal, constitute about 110 W for a ventilation system and only about 0.31 W for an LCG. This effect is attributable to the greater heat capacity (by a factor of about 10^3) of liquid, as compared to gas.

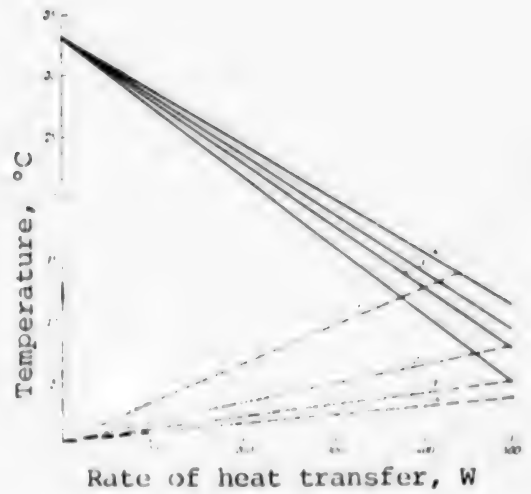

Figure 2.
Estimated heat carrier temperatures in LCG as a function of given heat removal [4]. Dotted line--temperature gradient between LCG input and output; solid line--temperature at input of LCG

1-4) mass velocity of flow, 30, 60, 90 and 120 kg/h, respectively

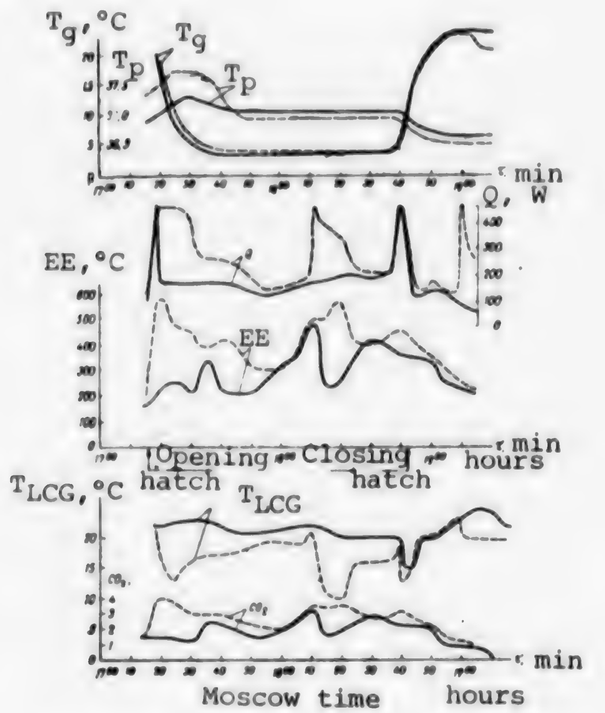

Figure 3.
Dynamics of changes in some parameters of heat transfer during extravehicular activity of cosmonaut on 15 July 1979. Solid line--commander; dotted line--flight engineer

T_p) body temperature in parotid region
T_g) temperature of ventilating gas at output from heat exchanger
Q) heat removal
EE) energy expenditure
T_{LCG}) water temperature at input to water-cooled garmet
CO_2) CO_2 content (vol.%) at input of absorbant cartrige at absolute pressure of 290-300 mm Hg

In spite of the high efficiency of systems of conductive heat transfer of the LCG type, use thereof advances several specific physiological problems. In the general physiological aspect, this is related to the fact that, under ordinary conditions, there is relatively low conductive heat exchange between the body and environment. In our case, however, this type of heat transfer becomes dominant. This circumstance has an appreciable influence on the choice of heat carrier temperature.

The results of studies revealed that, in the case where the temperature of surfaces coming in contact with the human body is below the optimum for a given level of heat production and area of cooled region, heat transfer at the early stage may even diminish, though this sounds paradoxical. This is attributable to the fact that, in response to the cold stimulus, a relatively prolonged (10 min or more) defense reaction of the organism may occur, manifested by constriction of skin vessels and, consequently, decreased transfer of heat from the nucleus to the membrane. Such a reaction is also associated with a sensation of discomfort.

Special studies revealed that if the cooling panel is of limited size one can solve the problem of maintaining temperature homeostasis over a rather wide range of heat loads by lowering significantly the temperature of the heat carrier at the input. Thus, if the panel has an area of the order of 0.1 m^2, man can tolerate well a temperature drop in the panel to 0-2°C with insulation at relative rest and to -5-7°C when performing moderately heavy physical work [7].

If such a panel is situated in regions with the most intensive heat transfer (for example, in the region of the back), heat removal will constitute about 116 W at relative rest and up to 325 W when working.

Obviously, this effect of heat removal by means of locally situated panels of a limited area expands substantially the possibility of using an LCG, particularly under conditions when it is difficult to use full LCG's because of the nature of professional work or constructive distinctions of gear.

As we have indicated above, the conductive method of heat removal inhibits the perspiration reaction. However, considering that, under real conditions of heavy physical loads, perspiration can still reach 0.2 kg/h or even more, the problem of removing this moisture from the human body arises. This problem becomes particularly acute in the case of using airtight insulating gear. For this reason, it is the most expedient to make combined use of the LCG and a system for ventilating the space under clothing.

The heat transfer that is effected in this case by the ventilating system has an interesting distinction. We refer to the specific nature of heat-mass transfer with the combined operation of the liquid and ventilation systems [8]. Cooling gas passes along the integument, is heated and moistened by perspiration evaporated from the skin surface and then reaches the LCG panel. There, the gas is cooled and water vapor contained in it is condensed. The cooled and dried gas passes on to aerate another part of the integument, then returns again to the LCG panel, etc.

An additional advantage of liquid heat-regulating systems is that they offer the opportunity to an experimenter of using them for "direct" calorimetry of man and, consequently, for dynamic recording of heat emission processes. One can make a tentative estimate of the amount of heat removed if one knows the outlay of heat carrier and difference between temperatures at the input and output of the system.

We can examine the extravehicular activity of cosmonauts V. A. Lyakhov and V. V. Ryumin on 15 August 1979, on the 172d day of the mission aboard the Salyut-6 station to release a radiotelescope antenna that was caught on it, as an example of successful practical use of a complex heat-regulating system in a space suit. In spite of the fact that there was some initial overheating of the cosmonauts while performing operations in preparation for extravehicular activity and great expenditure of energy while working outside the station, the ventilation and liquid-cooling systems not only normalized the thermal state of both crew members at the start of their work, but maintained temperature homeostasis during the entire period of extravehicular activity. The curves in Figure 3 graphically illustrate these statements. It must also be borne in mind that only water temperature at the input into the water-cooled garment (T_{LCG}) was a regulated parameter.

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EXPERIMENTAL AND GENERAL THEORETICAL RESEARCH

UDC: 613.693+629.78]:[612.13+612.824]-06:612.273.2.017.2

SYSTEMIC AND CEREBRAL HEMODYNAMICS IN FLIGHT PERSONNEL EXPOSED TO MODERATE HYPOXIA

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 15, No 6, Nov-Dec 81 (manuscript received 16 Mar 81) pp 16-19

[Article by V. N. Denisov, S. F. Rayev and I. I. Antuf'yev]

[English abstract from source] For the purposes of medical expertise the state of systemic and cerebral hemodynamics has been investigated in 66 pilots with autonomic-vascular instability and in 36 healthy subjects exposed to moderate hypoxia (in an altitude chamber). The pilots have shown noticeable tachycardia or systolic hypertension, as well as certain changes in cardiac output and stroke volume. These alterations have been accompanied by rheoencephalographic changes of two types one of which can be regarded as an adverse response of cerebral circulation to hypoxia. It is concluded that the study of systemic and cerebral circulation in hypoxia yields an important diagnostic information that allows better expertise estimates.

[Text] A set of functional tests is used in the practice of expert medical certification of pilots, in particular, testing in a pressure chamber for endurance of moderate degrees of hypoxia. Cerebral circulation plays a large part in the development of adaptation mechanisms for hypoxia, and one can indirectly determine the state thereof from the heart rate (HR), arterial pressure (AP), systolic and minute blood volume. Usually there is a certain correlation between changes in these parameters. However, this correlation may be impaired in the presence of marked tachycardia and arterial hypertension, and this makes it difficult to determine actual resistance to hypoxia. In such cases, determination of the state of cerebral and cardiac hemodynamics is important to evaluation of the pilot's reserve capabilities under hypoxic conditions.

Methods

Cerebral hemodynamics were examined in the presence of moderate hypoxia, with concurrent recording of filling of the right and left hemispheres with blood using frontomastoid leads with a 4RG-1 rheographic attachment. Stroke and minute volume was determined by tetrapolar rheography using an RPG 2-02 rheoplethysmograph. The rheoencephalograms (REG) and thoracic rheograms (RG) were recorded just prior to "ascent" in the pressure chamber, in the 1st, 7th, 15th, 30th min of exposure to hypoxia and after the "descent." Concurrently, HR and AP were measured.

We tested 102 flight personnel 19 to 53 years of age (average age 31 years), 36 of whom were in good health (average age 32 years), while 66 (average age 29 years) were diagnosed as having autonomic vascular insufficiency (AVI). The individuals with AVI were divided into 3 groups: the 1st group consisted of 12 people whose HR exceeded 114/min under hypoxic conditions; the 2d group consisted of 10 subjects whose systolic AP exceeded 150 mm Hg under hypoxic conditions; the 3d group consisted of 44 people whose HR and AP did not exceed 114/min and 150 mm Hg, respectively, under hypoxic conditions.

Results and Discussion

In the base state, the healthy subjects and those with AVI whose AR and systolic AP did not exceed 114/min and 150 mm Hg, respectively, under hypoxic conditions showed no appreciable differences in REG, HR and AP, which constituted the following values: pulsed filling of cerebral vessels 0.14, tonus of large cerebral vessels 12, 12.3%, arterioles 59.8-50.9%, veins 68.1, 68.8%, relative pulse volume 0.17-0.18 relative units, HR 80.0/min, AP 129.7 mmHg, index of heart function 104.5.

There was uniform increase in tonus of large vessels in both hemispheres from the very first minutes of exposure to hypoxia, as manifested by increase (by 17 4-17.9%, as compared to base data) in correlation between anacrotism time and REG wave time. Concurrently, there was some decrease in arteriolar (by 2.8-3.3%) and venous (by 4.3-5.7%) tonus, as indicated by the values of dicrotic and diastolic indexes; there was also increase in parameter of relative pulse volume (by 22.2-23.5%) and intensity of efflux, decrease in ratio between parameters of volumetric influx rate and volumetric efflux rate, which was indicative of more intensive cerebral circulation. After exposure to hypoxia, these parameters of cerebral hemodynamics conformed to base values.

In addition, in the 1st, 15th and 30th min of hypoxia there was an increase in HR (97.8, 93.9 and 91.1/min) and systolic AP (132.2, 133.9 and 131.4 mm Hg, respectively). This was associated with an increase of the index of heart function, $\frac{(AP_{syst} \times HR)}{100}$, to 134.4, 125.9 and 120.1, respectively; in the 2d-4th min after the aftereffect period this parameter constituted 94.5. Maximum increase of the index at the adaptation phase constituted 128% of the base value, and it dropped to 120% at the resistance phase. In over two-thirds of the cases, the functional level of cardiac activity rose by about 30% in both groups of subjects in the first few minutes of exposure to hypoxia, as compared to the base value, by no more than 20% in the 15th and 30th min, and it was about 20% below the initial level in the 2d-4th min of the aftereffect period. Thus, the physiological "cost" of burdening the heart to overcome the adverse effect of moderate hypoxia was highest at the adaptation phase.

In healthy subjects, during the pressure chamber tests the mean statistical parameters of stroke volume constituted 59.1±3.4 mℓ initially, 70.0-71.1±3.5 mℓ in the 15th and 30th min, and 8.0 mℓ above the base level in the 2d-4th min of the aftereffect period.

In subjects with AVI, who presented the same dynamics of changes in cardiac output, there was a tendency toward increase to 5.6 mℓ.

It is apparent from the above data that stroke volume had a tendency toward increasing at the adaptation phase in most subjects. The body used no more than 20% of the initial inotropic cardiac reserve. At the phase of resistance, further increment of stroke volume was close to the maximum. According to data in the literature, the latter may not exceed 30-40% and is utilized by the body mainly during light and moderate physical exercise.

Initially, minute volume constituted 4.8±0.26 ℓ/min, increasing to 6.3-6.6±0.3 ℓ/min in the 1st, 7th, 15th and 30th min of hypoxia, whereas it did not differ from the base value in the 2d-4th min of the aftereffect period.

A comparison of data referable to HR, index of cardiac function and its stroke volume shows that stability of minute volume at the adaptation phase was maintained chiefly by means of a positive chronotropic effect and at the resistance phase by a positive inotropic effect.

We could distinguish two types of REG changes in subjects with marked tachycardia. With the first type of reactions, relative pulse volume (0.23-0.21), tonus of large vessels (14.4-16.0%) were greater in the base state than in preceding groups of subjects, while arteriolar (47.8-47.3%) and venous (59.2-56.2%) tonus was somewhat diminished. Under hypoxic conditions, in the presence of marked tachycardia, the tonus of large vessels in the right and left hemispheres differed: it increased by 18.8% in the right hemisphere, as compared to base value, and by 5.6% in the left. There was more marked decrease in tonus of arterioles and veins (by 18.2-14 and 18.8-15%, respectively). In addition to change in vascular tonus, there was an appreciable decline of the rheographic index (by 14.3-15.4%), some elevation of parameters of relative pulse volume, intensity of influx and efflux of blood, increased blood flow rate (however, not identical in the right and left hemispheres). There were signs of lability of vascular tonus in both hemispheres. The apex of the RG flattened periodically, assuming at times the form of a plateau, or else it became sharper; the dicrotic notch either increased or periodically leveled off and shifted toward the apex. After discontinuing exposure to hypoxia, there was significant decrease in relative pulse volume (to 0.17) and rheographic index (to 0.11), as compared to base data. The other rheographic parameters conformed to base values.

In the same group of subjects, the index of heart function was 5-10% higher throughout the test period. Systemic hemodynamic changes differed little from those observed in the group of subjects with AVI, whose HR did not exceed 114/min under hypoxic conditions.

With the second type of reaction, the rheographic index, tonus of arterioles and veins, relative pulse volume and volumetric influx rate were lower in the base state than in the preceding groups. Under hypoxic conditions, we demonstrated a marked increase in pulsed filling of the brain and relative pulse volume, marked decrease in arteriolar and venous tonus and, after a brief increase, decrease in tonus of large vessels, slowering blood flow and then worsening of the subjects' general condition, as manifested by pallor, slower pulse and marked AP drop. This was associated with steep ascending anacrotism, sharper apex, well-marked increase in the incisura and dicrotic notch shifted toward the base of the rheographic wave, which was indicative of severity of vasodilatation. There was significant (as compared to base data) increase in tonus of arterioles and veins, as well as rheographic index, in the aftereffect period.

Unlike the indicators of subjects with AVI of the preceding groups, stroke volume was low both initially and under hypoxic conditions before development of a collaptoid state (by 13-14 and 19.7 mℓ, respectively). In some cases this parameter declined under hypoxic conditions, as compared to the base level.

The dynamics of changes in minute volume did not differ from those demonstrated in preceding groups; however, under hypoxic conditions, this parameter was lower by an average of 1.1 ℓ/min.

In subjects with marked systolic hypertension, just like those with marked tachycardia, we observed two types of changes in rheographic parameters.

With the first type of reactions, in the base state we demonstrated lower rheographic index and relative pulse volume, unlike parameters of subjects in the control group. Under hypoxic conditions, these subjects presented marked elevation of systolic AP and thereafter the nature of changes in rheographic parameters and systemic hemodynamics did not differ appreciably from the findings in the control group.

With the second type of reactions, intensity of pulsed filling of the brain, relative pulse volume and tonus of arterioles and veins were lower in the base state than in the control group.

Under hypoxic conditions, there was progressive rise of the rheographic index, somewhat less marked than in preceding groups of subjects with AVI, increase in relative pulse volume followed by decrease thereof, decreased tonus of large vessels, arterioles and veins, diminished volumetric influx and efflux rate with slowing of blood flow rate, which was associated with worsening of the subjects' general condition. At this time, the REG showed the same changes as in the group with marked tachycardia with worsening of the subjects' general condition.

Systemic hemodynamic changes also failed to differ much from those observed in the group with marked tachycardia when their general condition worsened.

Thus, intensification of cerebral hemodynamics, mainly with respect to increase in volumetric blood flow, was a beneficial reaction on the part of cerebral hemodynamics to hypoxia, including cases where marked tachycardia and systolic hypertension developed. There was increase in tonus of large and medium-sized cerebral vessels, with concurrent decrease in arteriolar and venous tonus, increase in blood flow rate. During the adaptation period, we observed maximum increase in level of function of the cardiovascular system, which diminished somewhat at the resistance phase, the minute volume remaining constant. At the adaptation phase, the latter persisted chiefly because of the positive chronotropic effect of the heart, whereas at the resistance stage the positive inotropic effect was more important.

The brief slight increase in volumetric blood flow at the adaptation stage and its subsequent decrease, which was associated with marked increase in pulsed filling of the brain and concurrent decrease in blood flow rate, as well as marked decrease in tonus of cerebral vessels, should be interpreted as an adverse cerebral hemodynamic reaction by subjects with AVI, with marked tachycardia and systolic hypertension under hypoxic conditions. Their minute volume was diminished, as compared to healthy subjects. The lower minute volume of the heart was attributable to diminished HR or cardiac output. Under hypoxic conditions, the latter became lower than the base level in a number of cases. The negative inotropic effect of

the heart, with decrease of cardiac output to the base level or lower, should apparently be considered one of the criteria of man's heightened sensitivity to hypoxia.

Thus, investigation of cerebral and systemic circulation under hypoxic conditions in flight personnel with autonomic vascular insufficiency yields important diagnostic information, which is necessary for making validated expert decisions.

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CAUSES OF FATIGUE AMONG CREWS OF CIVIL AVIATION HELICOPTERS

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 15, No 6, Nov-Dec 81 (manuscript received 25 Nov 80) pp 19-22

[Article by Yu. N. Kamenskiy]

[English abstract from source] Vibration and noise play an important part in fatiguing crewmembers of helicopters. The exposure to these factors during the flying shift results in an early and marked fatigue of pilots the level of which depends on the vibration effects to a larger extent than on the noise effects. The fatigue is followed by a decline of the psychophysiological parameters characterizing the visual and motor functions as well as the ratio of the basic processes in the central nervous system.

[Text] Investigation of the causes of fatigue among flight personnel is a most important prerequisite for assuring flight safety. It is believed that emotional tension in flight is the main cause of fatigue [1, 2]. Flights aboard civil aviation "linear aircraft" [airliners?] (LA) impose increased demands on the emotional sphere of pilots virtually only at the take-off and landing stages [3].

In the case of uncomplicated long-term flights in aircraft, emotional and physical deprivation due to the monotony of the situation and relative hypodynamia play the leading role in development of pilot fatigue [4]. These factors are virtually absent during flights aboard helicopters lasting no more than 1.5-2 h. For this reason, such concomitant factors as noise and vibration could play a large part in development of pilot fatigue [5-7]. Our objective here was to assess the role of noise and vibration in development of fatigue in helicopter pilots in the course of their routine work.

Methods

We examined the crews of LA of three types: Yak-40 aircraft (control group, 124 people), Mi-4 and Mi-8 helicopters (main groups, 147 and 140 subjects, respectively). The intensity of vibration and noise on the flight decks of these LA were not the same. In the cockpits of the Yak-40, the levels of noise and vibration were low [8], but considerable in the cockpits of the helicopters [9, 10].

The crews were examined 30-60 min before and 30-60 min after the flights. We measured critical fusion frequency (CFF), static tremor (ST), reaction to moving object (RMO) and reproduction of muscular exertion (RME). Intensity of noise and vibration in the cockpits was assessed in accordance with questionnaire answers.

To level off the emotional tension factor, which is present during take-offs and landings, we processed and analyzed the results of testing copilots (30 in each group). The age of the copilots in the control and main groups was 29±0.6, 27±0.5 and 29±0.5 years, respectively; the work [flight] load constituted 7.1±0.2, 7.3±0.1 and 7.1±0.1 h; there were 7.5±0.5, 8.2±0.5 and 8.1±0.6 landings per shift. We took into consideration the answers of all crew members in our analysis of the questionnaire data.

Results and Discussion

Most helicopter pilots complained of fatigue, tinnitus and headache after the work day. The Yak-40 pilots reported only fatigue. Psychophysiological parameters changed differently in different groups. In the control group, there was only a reliable decrease in CFF (by 6.5%); in the group of Mi-4 pilots there was a decrease in CFF (by 8.1%) and number of correct RMO (RMO_c) by 61.5%, with 20% increase in number of premature RMO (RMO_p). In the group of Mi-8 pilots, there was reliable decrease (by 4.8%) of CFF and RMO_c (by 55.6%), with increase in ST (by 27.8%), number of delayed RMO (RMO_d, by 18.5%) and RME error (by 62.2%)(see Table).

Changes in psychophysiological parameters of Yak-40 and Mi-4, Mi-8 helicopter crew members (M m)

Type of craft	Parameter					
	CFF, Hz	ST/s	RMO_c units	RMO_p units	RMO_d units	RME, arb. units
Yak-40	35,2±0,6 / 32,9±0,7	3,1±0,24 / 2,9±0,22	1,6±0,22 / 1,2+0,17	3,7±0,22 / 3,5±0,22	4,7±0,22 / 5,3±0,22	4,0±0,48 / 3,8±0,81
Mi-4	35,8+0,5 / 32,9±0,7	2,4±0,42 / 3,3±0,29	1,3+0,22 / 0,5±0,13	3,5±0,27 / 4,2±0,22	5,1±0,22 / 5,4±0,24	3,3±0,17 / 4,2±0,69
Mi-8	35,6+0,5 / 33,9±0,5	3,6±0,31 / 4,6±0,26	1,8±0,17 / 2,8±0,27	2,9±0,17 / 2,8±0,27	5,4±0,22 / 6,4±0,22	3,7±0,48 / 6,0±0,64

Note: Preflight data given in numerator and postflight in denominator

On the whole, the changes in psychophysiological parameters indicated that fatigue was considerably less marked at the end of the work day among Yak-40 pilots than helicopter pilots. These differences could be indicative of a somewhat different etiology of fatigue in the latter case. Unlike the Yak-40 pilots, helicopter pilots are exposed to intensive noise and vibration during flights. The answers to the questionnaires revealed that noise was perceived mainly as moderate and low (72.5% of the answers) in the Yak-40 cockpit, high and moderate in the Mi-4 helicopter cockpit (87.9% of the answers) and moderate (80.0% of the answers) in the cockpit of the Mi-8 helicopter. Of those questioned, 43.5% rated vibration as mild in the Yak-40 cockpit and 56.5% did not answer the question about intensity of vibration. In the Mi-4 helicopter cockpit, vibration was perceived mainly as moderate (51.5% of the answers), and in the Mi-8 helicopter cockpit as moderate and severe (61.6% of the answers).

Consequently, according to subjective estimates, the most intensive noise is present in the cockpit of the Mi-4 helicopter and the most intensive vibration in the cockpit of the Mi-8 helicopter, and this confirms with the physical characteristics of these factors [9, 11].

Apparently the high noise and vibration levels caused development of more marked fatigue among helicopter pilots during the flight shift than in pilots of aircraft of the Yak-40 type. One can judge the specific significance of these factors in development of pilot fatigue on the basis of investigation of the correlation between subjective estimates of vibration and the functional state of pilots. It was demonstrated experimentally that vibration plays the leading role as a fatiguing factor in the noise-vibration complex [12]. Evidently, this trend is also present in real flights. Many crew members of both types of helicopters reported that vibration was the most unpleasant flight factor (even in comparison to noise). However, while vibration of the Mi-4 helicopter was the most unpleasant to 30.3% of those questioned, this applied to 50% with regard to Mi-8 helicopters. At the same time, noise was considered the most unpleasant for about the same number of Mi-4 and Mi-8 helicopter pilots--12.1 and 13.3%, respectively. The other crew members rated noise and vibration as equally unpleasant: 57.6% of the Mi-4 helicopter pilots and 36.7% of the Mi-8 helicopter pilots. The predominant rating of noise and vibration as equally unpleasant factors in the cockpit of the Mi-4 helicopter, where the intensity of noise prevails, is also indicative of the leading role of vibration in the vibration-noise complex.

Objectively, we found that pilots of Mi-8 helicopters not only presented more marked fatigue, but a greater number of changed parameters, as compared to Mi-4 pilots: 3 parameters in Mi-4 pilots and 5 in Mi-8 pilots. The increase in RMO_p among Mi-4 pilots after flights may be indicative of deficient conditioned internal inhibition in the cerebral cortex, which disrupts the balance among the main neural processes, leading to disinhibition of excitation, and is typical of the early stages of fatigue [13].

The postflight increase in RMO_d among Mi-8 pilots is apparently related to attenuation of a more stable excitatory process, and it could be due to development and generalization of external inhibition, which is inherent in more marked fatigue [13]. This fact can apparently be attributed to the more intensive vibration in the Mi-8 cabin, which causes delivery of intensive impulsation to the cerebral cortex, particularly the motor centers. As a result, persistent muscular and nervous tension develops, which leads to marked fatigue [14]. The significant effect of vibration on the motor analyzer is confirmed by the substantial changes in RME parameter among Mi-8 pilots, whereas it changes to a lesser extent among Mi-4 pilots.

The low-frequency vibration in helicopters can be considered an adequate stimulus for the motor analyzer. Each mechanical oscillation elicits excitation of numerous mechanoreceptors located in muscles, bones, articulations and ligaments. The brain perceives impulses from mechanoreceptors as a signal that equilibrium is impaired, as a result of which there is reflex intensification and redistribution of muscle tone [14]. The powerful flow of impulses from mechanoreceptors first leads to prevalence of an excitatory process in the cerebral cortex and then to extensive inhibtion with concentration of excitation in the motor centers [15]. As a result, there is impairment of motor coordination, which is rather important in assessing helicopter pilot fatigue, since flying these LA involves performance of many strictly coordinated movements.

Thus, vibration and noise are among the chief causes of helicopter pilot fatigue. Exposure to these factors during the flight shift leads to premature development of fatigue, the degree of which depends on the intensity of vibration and noise.

Vibration plays the leading role in development of pilot fatigue in the noise-vibration complex.

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PHYSIOLOGICAL AND HYGIENIC EVALUATION OF VIBRATION IN THE COCKPIT OF A CARGO HELICOPTER

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 15, No 6, Nov-Dec 81 (manuscript received 19 Jun 80) pp 22-25

[Article by Yu. G. Matveyev and Yu. N. Kamenskiy]

[English abstract from source] In the cockpit of five helicopters the floor and the chair vibrated in a band of 8 Hz at a frequency of 112.5 and 114.0 dB, respectively. Before and after the flying shift 66 crewmembers were interviewed and examined. Vibration was referred to as the most unpleasant factor by 30.4% of them, noise was defined as the most unpleasant factor by 6.5% of them; 63.1% described both factors as similarly adverse. The level of psycho-physiological changes was proportional to the flight time. The first signs of fatigue were seen after flights of up to 5 hours in duration to increase drastically after flights of 6 and 7 hours.

[Text] During flight, the crew of helicopters is exposed to a number of ambient factors. Among them, vibration occupies an important place [1-3]. In order to solve problems of setting standards for vibration and to develop means of protection against it, a study was made of the correlation between statistical parameters of vibration in the work place, work schedules and functional state of subjects when performing commercial flights.

Methods

The characteristics of vibration at the pilot's work place were studied in the course of 30 commercial flights aboard 5 heavy cargo helicopters.

To record vibration, we registered the signal on magnetic tape, with subsequent processing on analog-digital vibration measuring equipment under laboratory conditions. The results were expressed in the form of averaged logarithmic levels of root-mean-squares of rate of vibration (referred to hereafter as vibration rate levels) in the range of octave bands with geometric mean frequencies F_c of 2 to 250 Hz. We also determined 90% confidence intervals of mean level of vibration rate [4]. Readings were taken on the cockpit floor and seat for three mutually perpendicular axes: OX, OY and OZ. For measurements on the chair seat, we used a steel sheet 300 mm in diameter and 4 mm in thickness. The three-component vibropack installed on the floor and steel sheet weighed 0.04 kg. Measurements

were taken during take-off, climb, in horizontal flight, during descent and landing.

The functional state of the body was evaluated by objective and subjective methods. We used professionally relevant methods: critical fusion frequency (CFF), static tremometry (ST), reaction to moving object (RMO) and reproduction of specified muscular exertion (RME). Anonymous questionnaires were used to study subjective perception of vibration [5]. The pilots were examined 30-40 min before and 40-60 min after the flight shift. Statistical evaluation of parameters of functional state of the body was made with probability of 95%.

Results and Discussion

As shown by the results of measurements, there is prevalence of low-frequency vibration (octave bands of 2.4 and 8 Hz) on the cockpit floor oriented vertically (OZ), corresponding to the harmonics of the rotor and vibration of the helicopter fuselage proper.

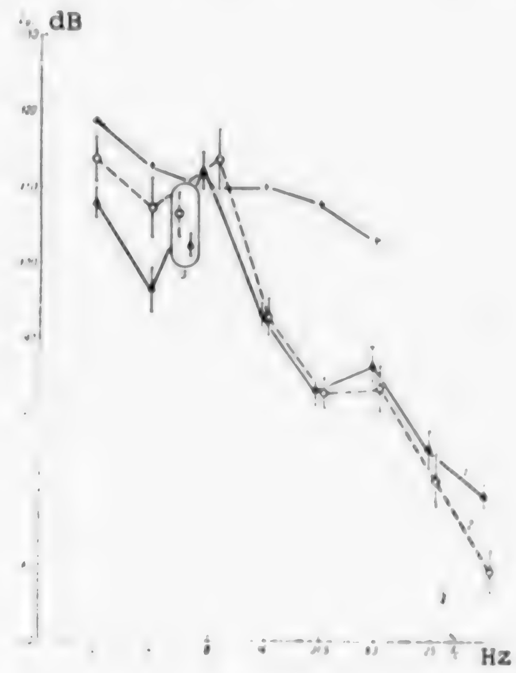

Figure 1.
Spectra of vibration rate levels in the pilot's work place. Vertical lines show 90% confidence interval for mean level of vibration rate
1) floor
2) seat
3) level of vibration in 8 Hz octave band on the floor (triangle) and seat (circle) in helicopter with installed vibration damper
4) spectrum of permissible levels of vibration rate according to GOST 23718-79

It was established that exposure to vibration during flight in a cargo helicopter is present for 90-98% of total flying time. The highest levels of vibration are observed at low speeds; however, duration of exposure to them does not exceed 2% of flying time. Consequently, the pilots' physiological reactions to vibration are determined by the levels of vibration during horizontal cruising.

The spectrum of vibration of the floor and seat in horizontal flight is characterized by levels of 112.5 and 114.0 dB, respectively, in the 8 Hz octave band. The pilot's seat damps vibrations at frequencies above 31.5 Hz, whereas in octave bands below 8 Hz there is intensification of vibration, which constitutes 9 dB in the 4 Hz octave band. The gradient of levels of vibration rate between the seat and floor constituted +6.0, +9.0, +1.5, -0.5, 0, -3.0, -4.0 and -10.0 dB at frequencies f_c of 2, 4, 8, 16, 31.5, 63, 125 and 250 Hz, respectively.

Studies in the field of industrial hygiene established that prolonged exposure to continuous vibration, as well as alternate periods of vibration and pauses, have a

substantial effect on the functional state of the organism. When there are pauses, there is significant attenuation of the physiological effects of vibration [6]. The work of cargo helicopter flight crews is characterized by differences in duration of flights t_f and intervals between them t_i. Time studies on the job established that the distribution of $P(t_f)$ and $P(t_i)$ can be approximated with the theorem of Kolmogorov [7] by normal distribution curves with a rather "hard" level of significance (0.2). These distributions presented virtually the same mean value and dispersion (Figure 2). About 80% of all the flights studied lasted 0.4 to 1.6 h. The most probable ratio of flight time to interflight intervals was 1:1.

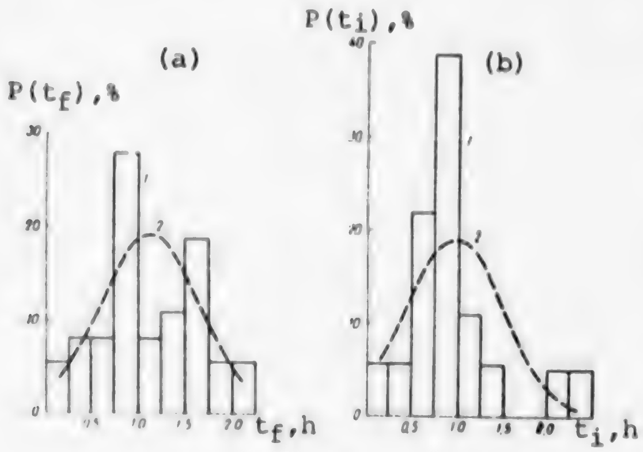

Figure 2.
Statistical distribution of duration of 30 commercial flights (a) and intervals between them (b).
1) observed distribution
2) normal distribution curve
a) mean is 1.12 h, dispersion 0.28 h^2
b) mean is 0.96 h and dispersion 0.28 h^2

A total of 66 crew members ranging in age from 23 to 40 years were questioned and examined in order to make a physiological and hygienic evaluation of the effects of vibration. Vibration of the work places was perceived as strong or irritating (84.6% of the subjects) and moderate or unpleasant (15.4%). As compared to other flight factors, vibration was considered the most unpleasant by most pilots. Thus, 30.4% of those questioned considered vibration to be the most unpleasant factor, 6.5% considered noise to be the most unpleasant, and for 63.1% vibration and noise were equally unpleasant. These data conform well with the results of studies that showed that operator fatigue during combined exposure to vibration and noise is related by 70% to vibration and only 30% to noise [8].

The degree of postflight change in psychophysiological parameters depended on flying time per shift, i.e., total exposure to vibration. With exposure for up to 5 h (24 cases) only accuracy of RMO changed reliably ($P<0.05$) by 26.3±6.1% (Figure 3). With exposure for up to 6 h (22 cases), all parameters worsened reliably: RMO by 27.4±9.0%, RME by 20.1±4.5%, ST by 21.4±10% and CFF by 2.0±0.6 Hz. The most marked adverse changes in the parameters were demonstrated with exposure for 7 h (20 cases): RMO by 50.1±8.0%, RME by 290±20%, ST by 21.3±8.2% and CFF by 4.2±0.8 Hz.

These psychophysiological changes were attributable to development of fatigue in crew members in the course of the flights. Work fitness of pilots [9] diminished.

In the case of marked fatigue, there is depletion of the body's psychophysiological reserves, and this leads to loss of the required performance qualities and lower level of flight safety. A complication of the flight situation against such a background could lead to a discrepancy in the pilot-helicopter system. There have been previous reports of cases of pilot disorientation, onset of illusions of spatial position and overturning of the helicopter under difficult flying conditions [10-13]. Helicopter vibration, which increases pilot fatigue and diminishes excitability of the vestibular analyzer, is one of the main causes of such situations [10, 14].

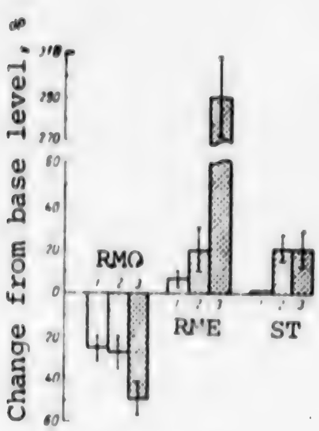

Figure 3.
Relative changes in RMO, RME and ST parameters in crew members after flights lasting 5, 6 and 7 h (1, 2 and 3, respectively)

All of the foregoing leads to the conclusion that it is necessary to set standards for vibration in the cockpits of helicopters in order to limit the effect of this factor on flight personnel. Proceeding from conventional principles of setting vibration standards [15], it can be considered that exposure to levels of vibration observed in this study should not exceed 5 h with $t_f:t_i = 1:1$. The curve of permissible levels of vibration rate in the range of octave bands from 8 Hz up will cross a point corresponding to a level of 114 dB. However, according to existing standards, the work load aboard heavy cargo helicopters constitutes 7 h per shift. For this reason, the curve of permissible levels of vibration was lowered by 4 dB in the abovementioned frequency range (see Figure 1) when GOST 23718-79 ("Aircraft and Helicopters, Passenger and Cargo. Permissible levels of vibration in passenger cabins and cockpits") was elaborated (see Figure 1).

In the present study, we observed premature development of marked fatigue in the pilots, which is related, in particular, with the high level of vibration in the cockpit [10]. Physiologically validated standards for flight work loads must assure the absence of marked signs of fatigue at the end of the work day. In this regard, the question arises of lowering vibration to which the crews of cargo helicopters is exposed. The most effective means of doing this is to damp vibrations at their source (active method). At the present time, pendulum-type dampers are gaining popularity, and use thereof lowers vibration to one-half to one-quarter. As shown by the results of flight tests, with installation of a pendulum damper aboard a cargo helicopter there is reduction of vibration to the level shown in the oval in Figure 1, which is appreciably less than the levels stipulated in Gost 23718-79. Limiting the flight load to 5 h is another means of reducing the effect of vibration on crews, and this reduces the overall effect of vibration per shift, as well as pilot fatigue (passive method).

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EVALUATION OF MAN'S ENDURANCE OF LOCAL PRESSURE TO THE HEAD AND OBJECTIVE ASSESSMENT OF HYGIENIC SPECIFICATIONS FOR PROTECTIVE HELMETS

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 15, No 6, Nov-Dec 81 (manuscript received 3 Dec 80) pp 25-28

[Article by V. M. Sinigin, Yu. G. Konakhevich, L. N. Sholpo and A. I. Uglanov]

[English abstract from source] To obtain reference data for a statistically substantiated evaluation of man's tolerance to the local pressure on the head (as applied to protective helmets kept on for a long time), 86 experiments were carried out in which 11 test subjects participated. The local pressure of 0.05-0.5 kg/cm^2 was applied to 8 areas of the head. The tolerance time was measured as the time interval from the beginning of the exposure to the emergence of localized sensations of the type: unpleasant, painful, very painful or intolerable. As a result, statistically significant relationships between the tolerance time and the level of the local pressure were obtained for the 8 locations and 3 grades of subjective sensations. These data can be used in evaluating protective helmets to be worn for a long time as well as in developing hygienic requirements for the advanced helmet-like devices.

[Text] The conditions under which modern aircraft are operated impose rather rigid requirements as to the quality of securing protective helmets (PH) on the operator's head. At the same time, in many cases, the pilot must wear this gear for many hours and this could cause unpleasant sensations, and in some cases pain.

The usual expert evaluation of relevant features of helmets can be objective enough only if there is extensive statistical material. A reliable evaluation of each new modification of PH requires lengthy studies with the participation of many subjects. Moreover, the problem of optimum PH design would probably be made simpler if there were statistical validation of standards of man's tolerance of local pressure on the head.

Methods

In order to obtain the necessary base data, we conducted specific studies, in which a special device (Figure 1) was used to create graded local pressure over different parts of the human head (Figure 2): in the frontal region over the midline (zone 1), midline of the parietal region (2), region of the external occipital eminence (3), in the parietal region near the left parietotemporal

pressure zones, as well size of contact surface of pressure setters was determined by the results of previous studies on prolonged wearing of PH. We conducted 86 series of tests with the participation of 3 men and 3 women 24 to 42 years of age (head circumference 56-61 cm). In the course of the study we graded the subjective sensations on the following scale: A--comfortable, B--unpleasant sensations, C--painful, D--very painful (intolerable).

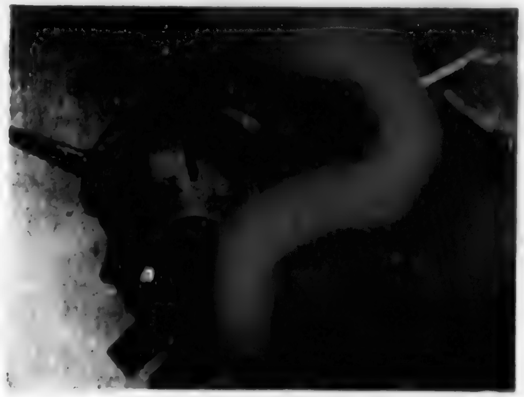

Figure 1.
General view of device for creating local pressure on the human head. Measurement of exertion on pressure setter.

Of course, subjective evaluation of sensations depends on both individual distinctions and variations of psychoneurological status of a given subject on different days. Since, however, the problem of objectivizing pain perception is far from being definitively resolved at the present time, statistical processing of subjective sensations seems to be the only available and rather valid method for the time being of assessing tolerance of such factors.

Local pressure on the head was created by means of a specially developed device (see Figure 1) weighing 0.66 kg. It consists of a rigid metal shell that can be individually adjusted, and pressure setters can be mounted on it. There are soft supports on the inside of the shell to assure its symmetrical position on the head. The contact surface thereof is larger by a factor of 10 than that of the pressure setter [controller], which precludes appearance of additional zones of local pressure due to reaction of the shell.

The pressure setter is a rod with a flat round surface (2 cm^2) on one end, which passes through a guide collar and is connected to the shell with flexible elements, the degree of tension and number of which determined the exertion on the rod measured with a spring dynamometer. The magnitude of exertion was recorded at the time of displacement of the rod in relation to the collar. The working length of the stretchable elements was so selected that a 2-3 mm shift of the rod due to deformity of soft tissues would not cause a change in magnitude of force applied to it by more than 5-7%.

The size of the contact surface of the pressure setter was governed, on the one hand, by the transverse length of typical sores (1-2.2 cm) which appeared when

wearing helmets and, on the other hand, by the need to have the contact surface of the pressure set lie uniformly upon the curvilinear surface of the head. It was established that a round pad ["platform"] 1.6 cm in diameter comes in uniform contact with soft tissues of the head in virtually all of the tested regions.

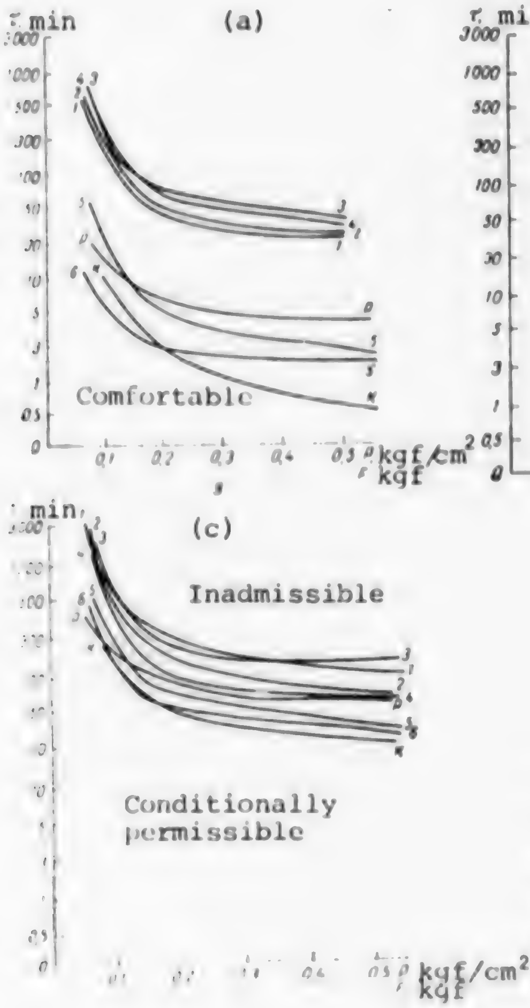

Figure 2.
Time of occurrence of "unpleasant" (a), "painful" (b) and "very painful" (intolerable) (c) sensations as a function of magnitude of local pressure (force) to different parts of the head. Explained in the text.

In the region of the tragus and edge of the auricular concha, pressure level was determined by the overall contact force, while estimated values of corresponding pressures were purely tentative, because of the difficulty of determining the actual area of contact between the pressure setter and skin (the scatter of contact area constituted 0.4-1.0 of the area of pressing surface).

The construction of the pressure setter made it possible to create local pressure in the range of 0.05 to 0.55 kgf/cm^2 (49-540 GPa [sic]). For regions T and AC, forces of 0.1-0.5 kgf (0.98-4.9 N) were used. Methodological studies established that it is not expedient to raise the top range, since in this case pain appeared within the first few minutes, while excess pressure of less than 0.05 kgf/cm^2 did not elicit any pain at all over an undetermined period of time (which is perhaps related to blood pressure level in the venous-capillary system of the skin).

Results and Discussion

In these studies, we determined the length of intervals between start of application of pressure to a given region of the head and onset of local sensations, "unpleasant" (τ_B), "painful" (τ_C) and "very painful (intolerable)" (τ_D). In assessing the conditions under wich the helmets are worn for a long time, the obtained times enabled us to consider that pressure to a given region of the head is comfortable if regular wearing time is $t \leqslant \tau_B$; it is permissible if $t \leqslant \tau_C$; it is conditionally permissible (for example in emergency situations), if $t \leqslant \tau_D$ and inadmissible if $t > \tau_D$.

The obtained values for τ_B, τ_C and τ_D were submitted to statistical processing using specially prepared programs on a 15VCM-5 microcomputer. In all, we processed 96 samples of values of τ (for 8 localizations of pressure, 4 levels of pressure and 3 gradations of subjective sensations).

The significance of differences attributable to the floor factor was assessed for each of the localizations according to the criterion of Student for sets with variants related in pairs. In all cases, the differences were insignificant for a confidence level of 0.95, for which reason the floor factor was not taken into consideration in subsequent processing. However, it is interesting to note that women presented appreciably better endurance of low levels of local pressure in some regions (particularly the parietal and occipital) than men; with high levels of pressure tolerance was about the same or even somewhat lower. Evidently, this is related to the cushioning effect of hair, which becomes irrelevant at high pressures.

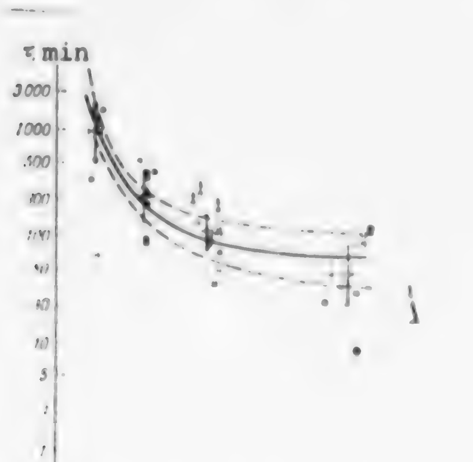

Figure 3.
Results of tests and approximating curves of time τ_C for region 1 (forehead). The solid line shows the regression function and dash line, confidence zones of regression for a significance level of 0.95

Each set was processed in a standard way, involving analysis and rejection of anomalous results, calculation of mean ($\bar{\tau}$), root-mean-square (σ) and standard ($\sigma_{\bar{\tau}}$) errors, confidence interval (δ) for significance level of 0.95, coefficients of asymmetry (A) and excess (E). Since the means ($\bar{\tau}$) were rather close to zero in a number of cases (in the range of $\sigma - 2\sigma$) and negative endurance times are physically meaningless, approximation of the sought distribution to Gaussian distribution was found not to be the optimum, because of "truncation" of the left branch of the distribution curve by the ordinate axis. For this reason, we used logarithmically normal distribution for approximation of the samples, which enabled us, in all cases, to reduce asymmetry to the permissible range and, in a number of cases, to lower excess coefficient E and reduce the number of anomalous discarded for formal reasons.

The logarithm of duration (τ) as a function of local pressure is close to hyperbolic, i.e., the results can be described by a function of the following type:

$$\log \tau = a - \frac{b}{Q} \qquad (1)$$

where a and b are constants, Q is local pressure level. By means of appropriate conversion, this function is reduced to a standard equation of linear regression whose parameters, as well as coefficients of correlation, are calculated by the usual methods.

In all cases, the coefficients of correlation were known to exceed the criticial tabulated values. Figure 3 illustrates an example of distribution of the obtained values with confidence intervals of time and pressure for a significance level of 0.95. As can be seen in Figure 3, a regression function of the (1) type approximates well the results of our studies.

From the standpoint of tolerance of local pressure when a PH is worn for a long time, the regions of the auricular concha (AC and T) and parotid regions of the head (5 and 6) are critical. These distinctions are particularly substantial in assessing comfortable pressure levels (see Figure 2a), they are less significant to determination of permissible pressure (see Figure 2b) and virtually insignificant for determination of conditionally permissible and inadmissible pressures (see Figure 2c).

The statistically significant functions we obtained can be used to assess the possibility of wearing various PH for long periods of time, so that the relevant work is reduced to testing several brief modes of local pressure under the PH (at the present time, the methods are undergoing the stage of laboratory testing). It is also desirable to use the obtained results in working out the hygienic specifications for future products of the PH type.

UDC: 629.78:[579.873.71:579.26."5"

EFFECT OF TRANSMERIDIONAL FLIGHTS ON BIORHYTHM OF ZONE FORMATION BY STREPTOMYCES LEVORIS

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 15, No 6, Nov-Dec 81 (manuscript received 10 Dec 80) pp 28-31

[Article by A. P. Savel'yev, A. Kh. Akhmadiyeva and I. G. Akoyev]

[English abstract from source] The transmeridioneal transportation of the temperature controlled colonies of Streptomyces levoris exerted a marked effect on its biorhythms. This included changes in the growth and zone formation rates and differences in the vector of changes as related to the flight direction. The vector of changes during the East-oriented air-borne flight coincided with that in the orbital flight with a similar direction of transportation. These findings as well as the results of studies of seasonal and diurnal rhythms of the actinomycete zone formation suggest the synchronizing effect of the periodicity of geophysical factors.

[Text] The mechanism of disruption of biorhythms during space flights has been little-studied as yet. Previously, substantial changes were demonstrated in the rhythm of cellular activity of multicellular organisms on the example of zone formation by actinomycetes during orbital flight. Experiments were conducted, which involved rapid transportation of the object under study in an eastward and westward direction, crossing nine time zones, in order to investigate the possible mechanism of these disturbances.

Methods

Streptomyces (Actinomyces) levoris Kras strain No 17-255A-IBFM (Pushchino strain) was the object of our study; it has marked zone-forming properties in the form of periodic formation of concentric rings of sporogenic aerial mycelium. The properties of this strain were described previously [1, 2]. The culture medium consisted of the following (in g/ℓ): Na_2HPO_4--12, KH_2PO_4--3, NaCl--1, $CaCl_2$--0.025, $MgCl_2$--0.15, NH_4Cl--1; in addition there was 10 mM glucose and 0.005% yeast extract, pH 7.0. The volume of nutrient medium was 6 mℓ (3 mm thick in 55x12 mm Petri dish). Spores from the fifth ring of a Streptomyces levoris colony divided in half served as inoculum at the Pushchino and Petropavlovsk-Kamchatskiy laboratories: one half served as material for inoculation in Pushchino and the other half in Petropavlovsk-Kamchatskiy. The cultures were inoculated by means of a puncture in the middle of the Petri dish. They grew in the dark at a temperature of 28°C. The

cultures were started at 0800-0900 hours local time, with the exception of specially mentioned cases. All colonies photographed were excluded from subsequent use in the experiment. The Actinomycetes colonies were transported transmeridionally from Moscow to Petropavlovsk-Kamchatskiy and back in "Termokont" containers at a temperature of 28°C, aboard passenger aircraft in a nonstop trip lasting 8 h and crossing 9 time zones. The same batch of nutrient medium was used to cultivate all batches of colonies cultivated in both Pushchino and Petropavlovsk-Kamchatskiy. For this purpose, the medium was decanted into Petri dishes, one batch of which was transported under sterile and sealed conditions to the laboratory in Petropavlovsk-Kamchatskiy and the other was left in the Pushchino laboratory under analogous conditions. The colonies were transported on the 6th day of growth. Analogous colonies in the laboratory, as well as batches inoculated in the interflight period, served as a control. Growth of Actinomyces was monitored by means of photography followed by measurement of negatives of 9-10 colonies from each batch (experimental and control) just prior to the flight, immediately after the flight, 3-5 days after the flight and then up to the 18th-22d day of growth. A seasonal periodicity of 3-5 days was observed for 3 years. In all, about 1600 colonies were examined.

Results and Discussion

Two experiments were conducted involving transmeridional transportation. Both were performed in September on about the same dates in 2 successive years. There were virtually no differences between the results of these experiments, so that they were combined on one graph (Figure 1). Our observation of colony growth after the 8-h flight from west to east through 9 time zones revealed that there was first a drastic then smooth increase in number of rings in the experimental group, as compared to the control. Growth of control groups inoculated at the second indicated time (Kamchatskiy and Pushchino) did not differ in either rate or distribution of σ. The experimental group transported from east to west demonstrated the opposite effect--drastic inhibition of zone-forming processes followed by increase thereof. We tested the hypothesis of synchronizing effect of the set of geophysical factors on biorhythms of the object under study in the laboratory by investigating the effect of the time, at which the culture was started, on rhythm of zone formation. The cultures were started on standard medium, all of which was prepared at the same time, at 0800, 1400 and 2000 hours on the same day. We found that the rhythm of zone formation depended on time of inoculation. The indicator of zone-forming rhythm (0.96) was highest with inoculation in the evening (2000 hours) and daytime (1400)--0.81 at each of these times, and lowest for morning (0800 hours) inoculations--0.7. In all of the cultures the dynamics of zone formation were such that all batches arrived at about the 15th ring at the same time. These findings are consistent with the 3-year

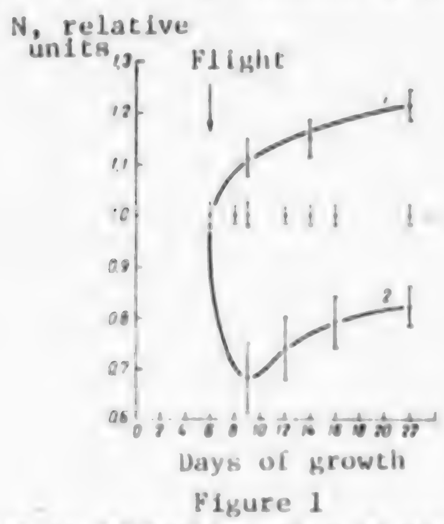

Figure 1

Change in relative number of rings after transmeridional transportation of Actinomycetes colonies eastward (1) and westward (2)

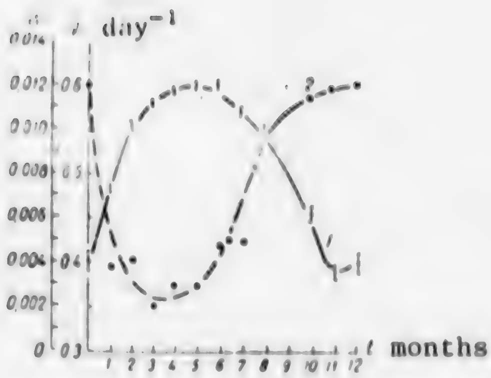

Figure 2.
Rhythm of zone formation ν as a function of season (1) and standard deviation σ (2) of this parameter

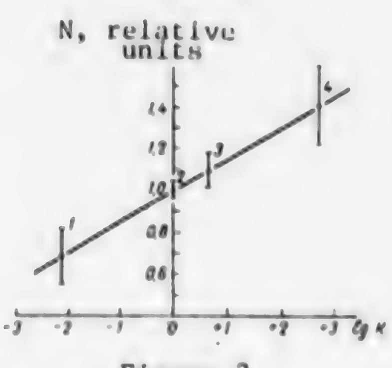

Figure 3.
Change in relative number of rings in Actinomyces colonies as a function of relative angular speed of travel. X-axis, ratio of angular velocity to angular speed of earth's rotation, log K; y-axis, ratio of number of rings in experiment to number of rings in control (in a stationary laboratory)

1) flight on aircraft from Petropavlovsk-Kamchatskiy to Moscow
2) flight on aircraft from Moscow to Petropavlovsk-Kamchatskiy
3) flight aboard orbital satellite (mean data from ASTP experiment)

observations of relationship of zone formation rhythm in Actinomyces to season (Figure 2), and as we had assumed the rhythm is related to seasonal fluctuations of geophysical factors. Minimum frequency ν of zone formation is observed in December and maximum in June. Standard deviation σ of frequency of zone formation is characterized by the opposite: minimum is observed in June and maximum in December.

We previously demonstrated that periodic zone formation of Actinomyces (i.e., rhythmic formation of rings of sporogenic aerial mycelium on the surface of the colonies) is a phenotypic manifestation of internal physical processes, and it is closely related to periodic differentiation of hyphae of substrate mycelium [2]. For this reason, the object we used enabled us to judge the effects of various exogenous factors on periodicity of processes controlling differentiation on the basis of changes in rhythm of zone formation.

Thus, it was demonstrated [2] that the type and concentration of oxidation substrate in the nutrient medium affect the rhythm of Actinomyces. As a result of many years of studies of rate of zone formation, it was also demonstrated that the season affects this parameter. Studies we conducted during the orbital flight aboard Soyuz and Apollo spacecraft [3-6] enabled us to expound the hypothesis that geophysical cycles have a synchronizing effect on rhythms of zone-forming processes in actinomycetes. Experiments involving rapid transmeridional transportation of the object eastward and westward confirm the validity of the advanced hypothesis. To further develop this hypothesis we compared data we obtained from experiments with Actinomyces involving transmeridional flights and on the Soyuz-Apollo (ASTP-75) program in order to search for a possible general pattern. We proceeded from the following theses: when traveling toward the east the object moves in the direction of earth's rotation and, consequently, faster than an object situated on its surface. When flying toward the west, the object moves in the opposite direction from earth's rotation. The angular speed of movement of the object in relation to earth's surface (dimensionless parameter K) can be calculated using the following formula:

$$K = \frac{t}{n + t}$$

where t is duration of the flight and n is the number of time zones crossed. A plus sign is used in the denominator for flights to the west and a minus sign for flights to the east.

The graph $N_{rel} = f(\log K)$, on which are plotted the results of experiments conducted in a ground-based laboratory, those during transmeridional flights to the east and west, and on the satellite, enabled us to assume that there is a general pattern (Figure 3). Travel to the east (both aboard an aircraft and in orbit) elicits an increase in relative number of rings. The faster the traveling speed, the greater this effect. Aboard a satellite flying eastward at a relative speed of K = 14.706, $N_{rel} = 1.43$, whereas in an aircraft flying in the same direction, with K = 2.125, $N_{rel} = 1.11$. Travel to the west (K = 0.125) elicits the opposite effect--decrease to 0.67 in relative number of rings. We were impressed by the fact that growth of variability of the effect (σ) is proportional to log K and is unrelated to the direction of travel.

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UDC: 612.76.014.477

SIMULATION OF SOME OF MAN'S MOVEMENTS IN DIFFERENT GRAVITY FIELDS

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 15, No 6, Nov-Dec 81 (manuscript received 26 Jun 80) pp 31-33

[Article by A. V. Zinkovskiy, I. A. Trofimova and V. A. Chistyakov]

[English abstract from source] The control of man's movements during adaptation to an altered gravity field was modeled by mathematical methods. Two types of movements were investigated: forearm displacement with various loads and repulsions from a support in zero-G and at high G's. It has been shown that movement coordination in altered gravity fields can be maintained due to a rearrangement of the control over muscle contraction which includes changes in the amplitude and pattern of joint momenta in harmony with the gravity changes.

[Text] The results of studies of man's vital functions during exposure to accelerations and weightlessness revealed that, in spite of change in the gravity field, coordination of man's movements is rapidly restored [1, 2]. Restoration of coordination is possible only if there is a change in control with due consideration of the change in the gravity field. In other words, to retain a skill there must be a change in force of muscular traction, i.e., articular momentum.

At the present time, there is no method to measure articulation momentums directly. Yet this parameter is of great interest, since articular momentums are the prime cause of motion and expressly they reflect the controlling action of the central nervous system, which forms muscular exertions that are adequate to the meaning of motion [3, 4].

We constructed here a mathematical model of man's movements in the vertical plane and dynamics of control in weightlessness and hypergravity, as well as determined the changes in dynamic structure of a motor skill providing for retention of man's coordination in space. As a mathematical model of man's movements, we took a kinematic chain consisting of links of specific [or known] dimensions, mass and inertia moments. Each limb was rendered as a simple open chain connected by kinematic pairs. All elements of the body, with the exception of the trunk and feet, were considered to be absolutely solid [hard]. Links of variable length simulated by means of cylindrical pairs were added to take into consideration deformation of the trunk and feet [5].

We used second order ["class"?] Lagrange equations to describe the dynamics.

A computer was used to make up the equations and then perform operations with them [6, 7]:

$$c_i \ddot{x} - d_i \ddot{z} + \sum_{k=1}^{n} a_{ik} \ddot{\varphi}_k - \sum_{k=1}^{n} b_{ik} \dot{\varphi}_k^2 = $$
$$= M_i - M_{i+1} - g d_i,$$
$$M \ddot{x} + \sum_{i=1}^{n} \left(c_i \ddot{\varphi}_i - d_i \dot{\varphi}_i^2 \right) = R_x \qquad (1)$$
$$M \ddot{z} + \sum_{i=1}^{n} \left(d_i \ddot{\varphi}_i + c_i \dot{\varphi}_i^2 \right) =$$
$$= -Mg + R_z,$$

where a_i and b_i are coordinates of center of mass of the ith link [member], M_i are articulation moments; and R_z are horizontal and vertical reactions in the support;* $\phi_i = \sum_{k=1}^{i} \psi_k$ (ψ_k are interlink angles); x and z are coordinates of points of contacts with the support.

Man's movements in weightlessness can be described by the equation if we assume that G = 0 in the system of equations (1). With increase in G we can obtain equations of movement in a field of increased gravity. A method was previously developed for determining muscular moments, which consists of the following [5]: the trajectories of movement are determined by means of photodiodes attached to a subject's articulations and a cyclophotographic [cycloramic photography?] device, after which, by means of smoothing spline functions, determination is made of velocity, acceleration and, by inserting them in equation (1) calculation is made of muscular exertion M_i. The results of the studies revealed that this method yields values that are consistent [adequate] with parameters of real human movements [5]. This enabled us to work out a measuring and calculating complex based on a single computer system for investigation of man's muscular function, and it was used for mathematical studies on a computer of the control of man's movements in different gravity fields. We examined two movements: moving objects differing in weight with flexion of the forearm and stopping man's movement followed by pushing away from a stationary support.

The choice of these movements was made for the following reasons. The first movement is elementary in structure, and this permits demonstration of changes in controlling muscle moments at different levels of gravity. Moreover, such movements are often encountered during cosmonauts' motor activity.

The study consisted essentially of the following. The movements studied were recorded by means of the cyclophotographic device on the ground. The first one was performed in erect position with the back on a support and immobilization of the shoulder. We recorded the intermember [interlink] angle $\phi(t)$ between the shoulder and arm.

The kinematics of the second movement were obtained by having a subject jump down from a low height and then jump up. We recorded the hip, knee and ankle intermember angles.

*Translator's note: There is an obvious omission here.

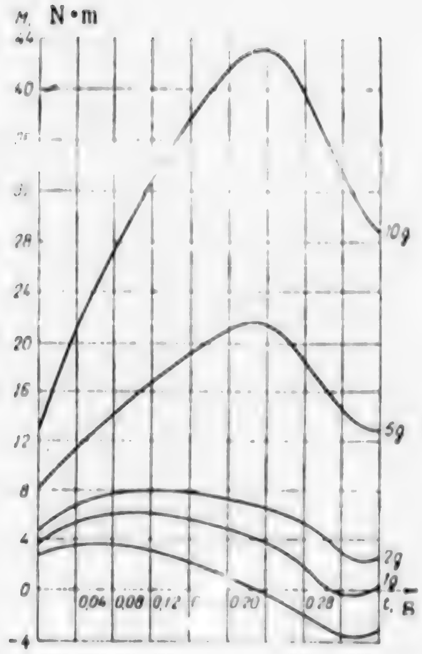

Figure 1.
Change in controlling moment M (muscle exertion, in N•m) at different levels of acceleration of free fall as a function of time

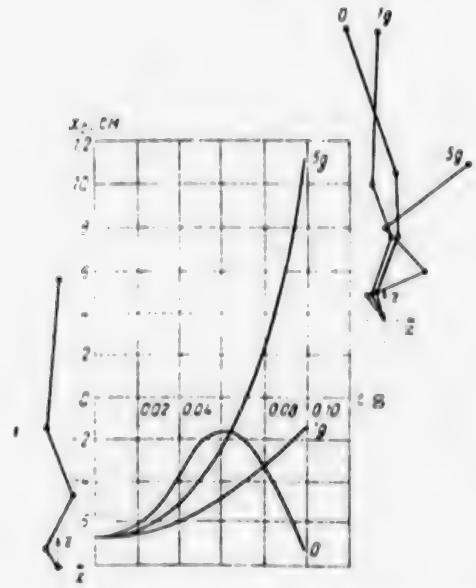

Figure 2.
Change in position of center of mass of system x_c (in cm) when jumping up at different levels of acceleration of free fall. Initial position of subject shown on the left and configuration when pushing away on the right

We then conducted a mathematical study whose objective included answering the following question: how should the controlling moments change so that the given kinematics of motion, i.e., motor skill developed on earth, would be retained in weightlessness and with accelerations?

Figure 1 illustrates the dynamics of controlling moment with displacement of the arm with a mass of 2.5 kg in fields with different levels of gravity (0 G, 2 G, 5 G, 10 G). When performing the specified movement in a field of gravity higher than on earth there is a change in amplitude of articulation moment that is proportional to the gravity force.

Performance of movement with specified kinematics of weightlessness occurs by means of alternation of the dynamic structure of movement. Thus, balancing of muscle tractive force by gravity is involved in stopping a moving member with shifting mass on earth. To stop the moving member in weightlessness, the sign of the articular moment must be changed, i.e., antagonist muscles must start to function.

In weightlessness, when man is stopped by a stationary support, in the presence of an initial impulse, the articular moments in the ankle and knee joints diminish. Stabilization of movement (stopping rotation about the support point) is achieved by means of appropriate compensatory rotation of the trunk in the opposite direction, which leads to increase or retention of momentum in the hip joint (as compared to the same momentum on earth). In the pushing away phase in weightlessness, the movement is performed at the expense of a reserve of kinetic energy, since the moments of the knee and angle joints undergo virtually no change; however, in

this case too, the momentum of the hip creates compensatory trunk movements which stabilize man's position in space.

If stopping ["inhibition"] and pushing away from a stationary support occur without prior adaptation, there is an excess (in weightlessness) or insufficiency (with accelerations) of movement, which distorts kinematics and, consequently, impairs coordination (Figure 2).

The results of this study revealed that the absence of "impact" dynamic loads is inherent in man's movements in weightlessness.

Thus, mathematical modeling on a computer of cosmonaut movements warrants the believe that retention of human coordination in altered gravity is provided by a change in control of the dynamics of muscular contraction, which is manifested by a typical change in amplitude of articular moments in time, in accordance with the changes in the gravity field.

The possibility of rapid restoration of coordination [1, 2] confirms once more the validity of the statement made by N. A. Bershteyn to the effect that "...movement is only possible with the most refined and continuous coordination, not provided in advance, of central impulses with phenomena occurring on the periphery...." [3].

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UDC: 629.78:[612.76+612.886

POSITIONS, MOVEMENTS AND EQUILIBRIUM OF RATS AFTER FLIGHTS ABOARD BIOSATELLITES

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 15, No 6, Nov-Dec 81 (manuscript received 28 Jul 80) pp 33-38

[Article by G. S. Ayzikov and A. S. Markin]

[English abstract from source] Examination of the Wistar-SPF rats flown onboard the biosatellites Cosmos-782, 936 and 1129 demonstrated significant changes in their postural, motor and equilibrium reactions. The use of artificial gravity inflight produced a beneficial effect on the health state, motor activity and simple reflex acts of the animals but worsened their movement coordination and equilibrium function.

[Text] Analysis was made of postural-motor and equilibrium reactions of rats after flights aboard biosatellites. Our objective was to determine the distinct phenomenology of these reactions, as well as to examine the animals' general condition in the preflight and postflight periods.

Methods

The objectives and conditions of conducting the experiments were described in detail before [1-3].*

In the preflight and postflight examination of the animals, we used cinematography and photography, methods for general and otological examination, with visual evaluation of otolithic reflexes ("ready to jump" reflex, elevator reflex, counterturning of the eyes in response to slow inclination). Positions, motor reactions and equilibrium function were tested by means of a device (Figure 1), which had three elements: a tunnel (to observe gait), run (to observe posture, orienting reflex and motor behavior) and a narrow bar over the run (to test equilibrium function) [4]. Equilibrium function was rated on a 5-point scale: 5--free movement on bar, 4--stable and prolonged stay on bar without losing equilibrium (sitting, turning around, limited movement), 3--staying on bar with difficulty in balancing and possible loss of equilibrium (without falling), 2--brief stay on bar with rapid loss of equilibrium and hanging on legs, 1--total inability to remain on the bar, falling. The grades for each group of animals were submitted to statistical processing. We also studied the "sticking" phenomenon that we observed: if a moving

*The following abbreviations are used in this article: IR--intact rats, R_{ag}--rats exposed to artificial gravity (AG), R^*_{ag}--animals put on short-arm centrifuge on the ground, SC--synchronous control, VC--vivarium control, LR--labyrinthectomied rats.

rat was suddenly covered with the palm and pressed slightly to the floor then immediately released it would lie motionless for some time, as if stuck to the spot. This phenomenon was rated as positive when the effect lasted about 1-1.5 s, marked if it lasted up to 2-3 s and very marked if it lasted over 3 s.

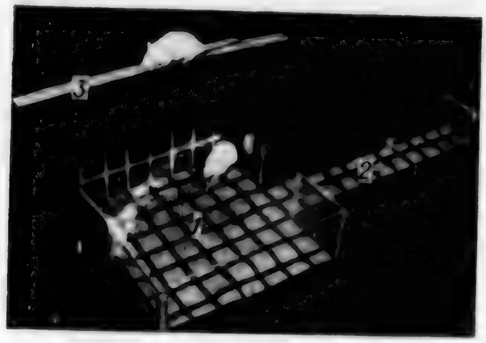

Figure 1. General view of device for examining gait, postural-motor reactions and equilibrium function

1) run 2) tunnel 3) bar

The animals were tested twice before the flight, 4-6 h after landing (0 day) and on the 1st, 3d, 6th, 11th and 24th days of the readaptation period. Ground-based control animals were examined at the same times.

The Table lists data on duration of biosatellite flights and number of animals in the examined groups

Scope of studies

Biosatellite	Flight duration, days	Number of animals examined							
		flight			control				
					SC			VC	
		IR	LR	R_{ag}	IR	LR	R^{*}_{ag}	IR	LR
Cosmos-782	19½	12	—	—	13	—	—	—	—
Cosmos-936	18½	5 (10)	5	5 (5)	5	5	5	5	5
Cosmos-1129	19	5 (5)	—	—	5	—	—	5	—

Note: The number of animals examined on 0 day is given in parentheses.

Results and Discussion

Preflight studies

Intact rats: Otolithic reflexes, motor activity and the orienting reflex were well-marked. The animals were active and passed rapidly through the tunnel. There were no pathological signs in their gait, with good support on all limbs, symmetrical

and smooth stepping motions; the rats waddled somewhat, rocking their trunk in rhythm with stepping. The "sticking" phenomenon was positive. The animals went out of the tunnel cautiously, as if slinking and occasionally stopping for a while. The first passages through the run were made in short runs that gradually became longer. After getting out of the tunnel, the rats cleaned their fur, "washed" and lay down. In this position, the paws were symmetrically tucked under their belly. The animals moved freely and rapidly on the bar, easily changing direction of movement, sitting stably across the bar, dropping without difficulty into the run along the struts of the bar (Figures 2 and 3).

Labyrinthectomied rats.* Motor activity and the orienting reaction were quite different in LR, as compared to IR. The LR were excessively active. Their movements were abrupt, angular and often poorly coordinated. The rats moved rapidly and chaotically over the run, stopping suddenly and abruptly changing in direction, and they roved about. The latter sometimes alternated with walking in a circle, mainly in one direction. The "sticking" phenomenon was absent. There were various degrees of neurological symptoms: ataxia and throwing their heads back, torsion spasm and intentional tremor. These symptoms diminished or disappeared during the scratch or "washing" reflexes, as well as when lying down, and they were accentuated while walking, maintaining a position and equilibrium. The animals ran rapidly through the tunnel, with the head and trunk somewhat inclined, and did not stop before going into the run. Their gait was rushed, waddling and often ataxic. Occasionally, we observed brief loss of equilibrium when turning around or stopping suddenly, as well as when trying to assume the "kangaroo" position. They rarely succeeded in the latter. LR were mainly in seated position on the bar, balancing themselves markedly with the tail and trunk. They presented drastic intensification of ataxia of head movements, which made it difficult to retain equilibrium and the rats suspended themselves with the back down. Some animals fell as they tried to walk on the bar.

Postflight Studies

Intact rats: After landing, most of the rat fur was moist, occasionally sticky and soiled by excreta. There were no otological changes and otolith reflexes were intact. The animals were sluggish, apathetic, their movements were slow and uncertain. They moved spreading the hind legs widely and rocking markedly; they often stopped and lay down. Some animals sprawled when they lay down, occasionally moving by crawling. They could not stay on the bar, lost their equilibrium and, after hanging on for a short time, fell off.

On the following day, the condition of the animals improved. They were moderately active, groomed themselves, "washed" and slowly moved into the run. They rocked when walking. Their gait was "creepy" with the trunk low, and the hind legs were not completely straightened out. We failed to observe attempts at looking beyond the run or assuming the "kangaroo" position. There was a very marked "sticking" phenomenon. They passed through the tunnel stopping 2-3 times, occasionally lying down. When lying down the position of one or both hind legs was unusual for this position: they protruded from under the belly with the toes spread out and unnatural pronation of the crus (see Figure 2b, 2). The rats did not elevate their trunk when changing position or turning on their side when lying down, as if dragging the trunk by means of active movements of the front legs, whereas the

*The labyrinthectomy was performed by A. V. Mokrousova by electrocoagulation [5],

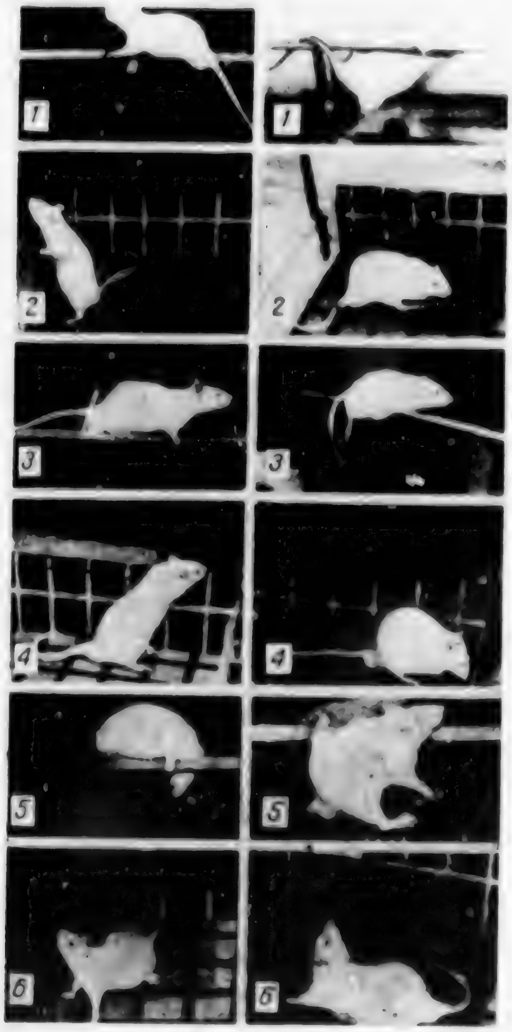

Figure 2.
Photographs of the animals in the test devices before flights (a) and right after landing (b) [letters not included on photos]
1, 2) intact rats
3, 4) animals submitted to artificial gravity
5, 6) labyrinthectomied rats (1, 3, 5--equilibrium on bar; 2, 4, 6--position in run)

hind legs followed the trunk passively. The muscles of the front legs were functionally the best preserved with regard to nature of activity and participation in movements and the least preserved were those of the hind legs. The animals could only sit on the bar. When they tried to move, they experienced considerable difficulty in controlling the hind legs, which slipped off constantly and the rats, losing their equilibrium, would hang on their front legs.

On the 3d day, there was considerable improvement of the animals' condition. The rats were quite active, often rose on their hind legs peeking out of the run (but they did not support themselves on their digits), occasionally assuming the "kangaroo" position, but not holding in this position and occasionally losing their balance. They ran rapidly through the tunnel, extending their limbs completely and placing them firmly ["harshly"] on the support. Motor activity and the orienting reaction did not reach preflight levels. The rats were still somewhat inhibited. They sat well and stably on the bar, and some moved on it. There was a marked "sticking" phenomenon.

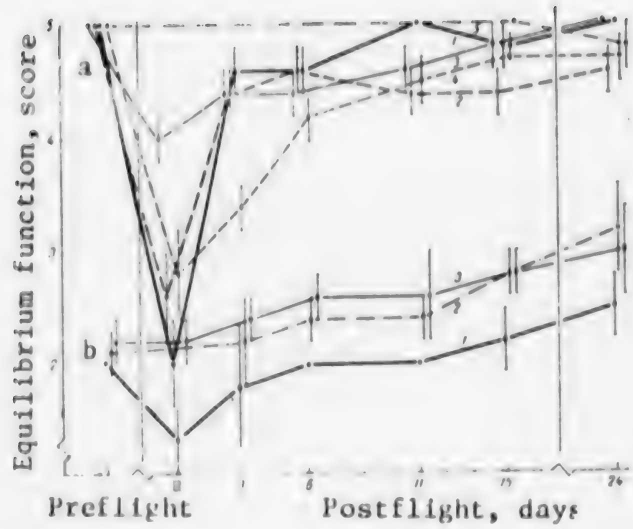

Figure 3.
Curves of changes in equilibrium function in intact (a) and labyrinthectomied (b) rats

1) weightlessness
2) artificial gravity
3) synchronous control
4) short-arm centrifuge
5) vivarium control

On the 6th day, the animals' condition was good. Motor activity and orienting reflexes did not differ from base levels. There were only negligible changes in gait and some difficulty in walking on the bar. The "sticking" phenomenon was positive. Thereafter, there was complete normalization of postural and motor reactions. Walking on the bar remained difficult.

Labyrinthectomied rats: After landing, the appearance of LR did not differ from that of IR. Motor activity was rather high, but lower than before the flight. They passed through the tunnel stopping frequently and for a long time. They roved about the run chaotically, stumbling, sometimes walking in a circle and often losing their balance. There was significant increase in ataxia. All movements were associated with nodding movements and/or tremor of the head. They could not hold on to the bar and, in most cases, fell down, without hanging on for a while with their legs. The "sticking" phenomenon was positive. By the 11th-15th day of readaptation, the level of motor activity and nature of behavioral reactions of some animals were similar to those of LR in the ground-based control experiments. Equilibrium function remained poor, and there was a tendency toward improvement toward the end of the study.

Rats exposed to AG: On the day they landed, the condition was good, fur was clean and dry. The rats were active. There was a marked orienting reflex (see Figure 2b, *4*). The animals passed rapidly through the tunnel and they were active in the run, moving frequently, peeking over the wall, standing on their hind legs (but not using digits for support). There was considerable worsening of equilibrium function: they were slightly rocky when walking fast, and they could not assume the "kangaroo" position. They had difficulty sitting on the bar, balancing themselves markedly with the trunk and lost their equilibrium rapidly, handing with their back down. There was a marked "sticking" phenomenon. By the 11th-15th day of the readaptation period there was virtual normalization of postural-motor reactions and equilibrium function.

Study of Animals in Ground-Based Control

Intact rats: No appreciable deviations of postural-motor reactions and equilibrium function were noted in the VC group of animals. The "sticking" symptom was

positive. Some animals presented an insignificant decrease in motor activity and equilibrium function when last examined. In the SC group, there was some inhibition, relative worsening of equilibrium function and marked "sticking" phenomenon on 0-3d days. These changes rapidly disappeared and thereafter the characteristics of SC animals showed virtually no differences from those of the VC group.

Labyrinthectomied rats: The general condition and tested reactions were the same in the VC and SC groups of animals. There was gradual decrease in motor activity, ataxia and forced movements. By the 24th day they were minimal and, in some animals, lacking. Equilibrium function improved. However, the aftereffects of labyrinthectomy were readily demonstrable in tests or stiuations requiring immediate and precise motor decisions (maintaining a stable position, retaining balance on the bar, etc.).

Rats exposed to AG. R_{ag} appeared sluggish and depressed. Their motor activity and orienting reflex were inhibited. They went through the tunnel slowly, stopping at the exit, often walking in circles. Their gait was shaky. They lost their balance when trying to assume the "kangaroo" position. They did not sit much on the bar, trying hard to balance themselves, often losing their equilibrium and hanging on their paws. By the 11th day of the study, the postural-motor reactions and equilibrium function were normalized.

The data we have submitted convince us that a long-term space flight has a significant effect on the animals' condition. There is a change, primarily in motor activity and orienting reactions. Maximum changes were observed among IR and they were less marked in LR animals submitted to AG. For the latter, the minimal postflight results of tests are related to their exposure to artificial gravity, close to that of earth. This could be evaluated as the normalizing effect of AG on some motor functions of the animals. However, the distinctions of the created AG with a short-arm centrifuge and high angular velocity of rotation lead to some undesirable consequences, since they are associated with occurrence of precession and Coriolis accelerations, as well as an AG gradient. These factors probably have an adverse effect on coordination, equilibrium reactions and precise motor acts. Adverse effects were demonstrated in these rats in studies of higher nervous activity [6], as well as osteogenetic processes [7].

At first, the LR presented heightened motor activity, probably attributable to inclusion in spatial analysis and coordination of movements of "backup" sensory systems. Such a response to inactivation of the labyrinths apparently persists during a space flight, eliciting a certain conditioning effect in weightlessness and better condition of the animals after landing. It is also known that LR readily adapt to weightlessness [8] and show virtually no restriction of movement during the space flight, unlike the IR. Probably, the absence of the vestibular system is the cause of less reactivity of LR to abrupt changes in afferent influences with change in gravity. Analogous findings were made in ground-based experiments and during short-term weightlessness [9-11]. As a result of the postflight studies, we also demonstrated deterioration of the tested parameters in LR. There was intensification of ataxia and tremor of the head, as well as more frequent throwing of the head back. As compared to LR of the ground-based control, they presented a delay in compensation of the vestibular defect and intensification of cerebellar symptoms.

After the space flight, all animals presented drastic worsening of equilibrium function. On 0 day, in IR it was comparable to that of LR in the vivarium and

synchronous control groups. Similar changes were also present in R_{ag} and R^{*}_{ag} animals. On the 3d-6th days of the readaptation period there was intensive recovery of equilibrium function. By the 24th day, equilibrium reactions of flight and control animals were virtually the same. In IR, they were somewhat less marked than before the flight or start of synchronous experiment, which is apparently related to age-related changes. Yet the LR of control groups presented progressive improvement of equilibrium function. The reliably higher level thereof, as compared to base data, on the 15th day was indicative of consistent build-up of compensatory processes. In LR, analogous changes occurred after the flight but on a lower level, and they were evaluated merely as a tendency toward improvement. By the 24th day of readaptation, their parameters of equilibrium function were somewhat above (not reliably) preflight levels. This is another manifestation of delayed compensation, which is probably related to inactivity of skeletal muscles and prolonged lack of support. On the ground, similar effects were obtained when the animals were suspended, submitted to chordotomy and transection of dorsal radices of the spinal cord [12-14], when there was elimination or attenuation of influx of tactile and proprioceptive stimuli to the central nervous system and vestibular nuclei.

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CATHEPSIN ACTIVITY OF SKELETAL MUSCLE AND MYOCARDIAL MYOFIBRILS AFTER EXPOSURE TO WEIGHTLESSNESS AND ACCELERATIONS

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 15, No 6, Nov-Dec 81 (manuscript received 26 Jun 79) pp 38-42

[Article by S. S. Oganesyan and M. A. Eloyan]

[English abstract from source] The rats flown onboard Cosmos-605 and exposed to a synchronous experiment for 22 days showed an increased activity of myofibrillar cathepsins in skeletal muscles of different groups. In the flight rats the increase was greater than in the synchronous ground-based animals. This suggests a significant effect of weightlessness on the cathepsic activity. The parameter was partially normalized at R+ 25 or 26. The exposure of rats to accelerations of 4 and 5 G for 20 min daily during 2 weeks also increased the cathepsic activity of skeletal and myocardial myofibers. The parameter returned to normal a month after completion of acceleration exposures. Thus, changes in the proteolytic activity of myofibers of different muscles induced by weightlessness and acceleration are reversible. The significance of changes in the muscle tension as related to the mechanism of stimulation of proteolytic reactions is discussed.

[Text] Expansion of space flight programs and the need to prolong man's stays in space makes it necessary to predict the reactions of different groups of skeletal muscles to weightlessness and accelerations caused by flights. A change in protein metabolism is an important element in the mechanism of muscular adaptation to a new functional mode. In recent years, it was established that the rate of renewal of muscular proteins is not the same in skeletal muscle fibers that differ in speed and force of contraction. Very rapid renewal of myofibrillar proteins is inherent in red, slowly contracting muscles that have an antigravity function, whereas the rate of replenishment of proteins of white, rapidly contracting muscles, which function with a small load, is considerably slower [1-3]. It can be assumed that the changes in biomechanical mode of function would induce different degrees of change in protein composition of different groups of skeletal muscles. It is deemed important to determine the activity of enzymes of catabolism of muscle proteins in studying the mechanism of this phenomenon, in view of the fact that the rate of degradation of proteins may vary under extreme conditions, regardless of synthesis thereof [4].

There has not been sufficient investigation of the question of direct involvement of different proteases and cathepsins in catabolism of myofibrillar proteins. Some

authors have called attention to neutral proteases and acid cathepsins, which were demonstrated in unpurified myofibrils and preparations of contractile and regulatory proteins of muscles and the myocardium [2, 4-6]. Among these enzymes, cathepsin D, which is widely distributed in muscle tissue, as well as the recently discovered proteolytic enzyme that is activated by calcium and disrupts the Z line of myofibrils [7], have drawn particular attention.

The question of attribution of cathepsic activity to myofibrillar proteins was the subject of our special investigation [8, 9]. We succeeded in demonstrating that it is due to admixtures of cathepsin D and, to some extent, cathepsin A in incompletely purified preparations of myosin, actomyosin, tropomyosin and troponin. At the same time, purified myofibrils also demonstrate proteolytic activity and contain an adequate amount of cathepsin D which, according to preliminary data, is not of lysosomal origin [8]. The fact that myocardial myofibrils present maximum cathepsic activity, red skeletal muscle fibrils have somewhat less such activity and white skeletal muscles the lowest activity is attributable to the existence of a certain correlation between intensity of renewal of muscle proteins and cathepsin activity of myofibrils [3]. In other words, we can assume that there is a correlation between mode of function of muscle fibers, intensity of renewal of proteins and cathepsic activity of myofibrils which, as it has been demonstrated, plays some part in regulation of catabolism of contractile protein [10]. All this served as grounds to investigate cathepsic activity of myofibrils in order to demonstrate the reactions of different types of muscles to space flight factors.

Methods

We conducted our study on Wistar albino rats. In the first series of studies, we examined cathepsic activity of myofibrils of skeletal muscles of two groups of animals: rats flown for 22 days in space aboard the Cosmos-605 biosatellite who were examined on the 2d and 26th postflight day and animals used for 22 days in a ground-based model experiment, in which all space flight factors were reproduced, with the exception of weightlessness. Groups of animals kept under the usual vivarium conditions served as a control.

In the second series, we studied the effects of accelerations created by means of a centrifuge. The animals were divided into three groups: the 1st group was centrifuged for 12 days, 20 min a day, at accelerations of 4 G and the 2d group for 40 min a day for 14 days at 5 G. They were examined on the 2d day after rotation on the centrifuge. The 3d group consisted of animals centrifuged for 20 min a day for 30 days, at accelerations of 4 G, and they were examined 1 month after these accelerations to evaluate readaptation changes.

We examined the myocardium and following skeletal muscles: long and common extensors of the toes of foreleg, biceps and triceps of foreleg, quadriceps, semimembranous muscles and posterior group of thigh muscles.

The myofibrils were prepared by the method of Perry [11] as modified by Matsuki [12]. The obtained myofibrillar preparations were characterized by high ATPase activity, which was not depressed by 5 mM sodium axide, as well as absence of acid phosphatase, which was indicative of adequate removal of lysosomal enzyme admixtures from the myofibrils.

We assessed cathepsic activity of myofibrillar extracts on the basis of dissociation of denatured hemoglobin of ox blood [13]. The amount of tyrosine released upon lysis of hemoglobin was determined spectrophotometrically from the standard curve. Hemoglobin was incubated with myofibrils for 60 min at 37±0.02°C, pH 3.5. We determined the protein concentration in myofibrillar extracts according to the biuret reaction.

Results and Discussion

Cathepsin activity of myofibrils of the biceps, quadriceps, semimembranous muscles and posterior muscle group of the thigh of control animals was characterized by levels of 6.0 to 8.1 μg tyrosine per mg protein. The myofibrils of the triceps, as well as long and common extensor of the digits of the front leg presented somewhat higher activity--9.5 to 13.3 μg tyrosine/mg protein. The absence of major differences in cathepsic activity of myofibrils of the skeletal muscles studied can apparently be attributed to the similarity of their functional profile and presence of different types of fibers in them. The preparations of myocardial myofibrils presented considerably higher cathepsic activity (Table 1). The relatively high cathepsic activity of extensors of the digits of the front leg causes them to resemble the red muscle fibers and myocardium, which are characterized by faster renewal of proteins.

Table 1. Cathepsic activity of myofibrils of different groups of skeletal muscles and myocardium of normal white rats (M±m)

Muscle	Cathepsic activity, μg tyrosine/ mg protein (37°C, 60 min)	Number of preparations examined
Biceps	6.0±1.6	20
Triceps	9.5±0.5	17
Quadriceps	7.8±1.9	20
Common and long extensors of front digits	13.3±1.9	27
Posterior muscle group of thigh	7.9±1.7	30
Semimembranous	8.1±1.8	20
Myocardium	23.3±1.7	20

The data obtained 2 days after the 22-day space flight revealed significant intensification of enzymatic activity in all tested groups of skeletal muscles. Cathepsic activity was about 2.5 times higher than in the control (Table 2).

After the ground-based experiment, which simulated space flight conditions, cathepsic activity of myofibrils was considerably higher than in the control, but lower than the postflight levels. This warrants the assumption that the weightlessness factor elicited additional increase in cathepsic activity of myofibrils, intensifying dissociation of muscle proteins in skeletal muscles. The studies conducted 26 days after the flight revealed an overt tendency toward decline of cathepsic activity, although it was still about 1.5 times higher than in the control.

In the second series of studies, it was demonstrated that exposure to 4 G accelerations for 20 min a day for 2 weeks caused a significant increase in cathepsic activity of myofibrils of skeletal muscles and the myocardium (Table 3).

Table 2. Changes in cathepsic activity of skeletal muscle myofibrils of white rats after flight and ground-based experiment (M±m)

Muscles	Animal group	Days after 22-day space flight		2 days after termination of ground-based synchronous exper.
		3	26	
Triceps	Experimental	24,8±1,1	16,1±0,4	19,0±0,5
	Control	9,0±1,6	10,2±0,5	9,4±0,4
Long and common extensors of foreleg digits	Experimental	35,3±1,7	21,9±0,3	26,6±1,0
	Control	13,3±0,6	14,4±3,3	13,4±1,8
Posterior muscle group of thigh	Experimental	19,5±0,7	11,7±0,9	17,4±0,9
	Control	8,4±2,9	7,2±1,1	8,1±2,9
Quadriceps	Experimental	—	—	19,8±2,9
	Control	—	—	7,5±0,3
Semimembranous	Experimental	—	—	17,3±0,8
	Control	—	—	8,8±1,2

Table 3 shows that no additional increase in cathepsic activity was demonstrable under the effect of more intensive accelerations (5 G for 40 min daily, for 14 days). One month after exposure to 4 G accelerations the cathepsic activity of myocardial and skeletal muscle myofibrils was the same as in the control group. Consequently, myofibrillar cathepsic activity was activated almost entirely under the influence of 4 G accelerations and reverted to the initial level 1 month after discontinuing exposure to accelerations, regardless of the type of muscle (see Table 3).

Table 3. Effect of accelerations on cathepsic activity of myocardial and skeletal muscle myofibrils of white rats (M±m)

Animal group	Myocardium	Skeletal muscles
Control	23.3±1.7	14.4±1.6
First	37.1±2.6*	25.1±2.7*
Second	37.0±1.8*	26.8±2.0*
Third	23.3±1.8	15.2±1.1

*P<0.001

These data indicate that decrease in the load on skeletal muscle fibers in weightlessness, like the effect of accelerations, elicits a reversible increase in cathepsic activity of myofibrils.

With reference to the possible mechanism of this phenomenon, it should be stressed, first of all, that we actually determined cathepsin D activity in this study. This enzyme has optimum activity in the pH range of 3.5-3.8; it is demonstrable in adequate amounts in intracellular particles of muscle cells, and it is characterized by the presence of three isozymes differing in molecular mass [8, 14, 15]. Cathepsin D is important to both catabolism and anabolism of muscular proteins [16-18]. Apparently, it is involved in renewal of myofibrillar proteins, binding with them when isolated [8-10], and addition of cathepsin D to a homogenate of muscles enhances

autolytic processes [19]. On the other hand, there are indications that it is involved in development of both atrophy and hypertrophy of skeletal muscles [3]. Indeed, in animals submitted to centrifuging, the increase in cathepsic activity was associated with increase in mass of the heart, which increased in the white rats of our experiments on the average from 756 to 800 mg with 4 G accelerations and up to 1200 mg at 5 G.

The mild atrophy, decrease in force and tonus of muscles of the lower limbs of cosmonauts after long-term flights are indicative of increased intensity of proteolysis of myofibrillar proteins of skeletal muscles [2, 24]. In experimental animals, a decrease in synthesis of myofibrillar proteins and muscular atrophy were demonstrated after the space flight. These changes could be related, in particular, to intensification of degradation of myofibrillar proteins in red muscles [20]. Perhaps, the observed metabolic disturbances are also attributable to intensification of proteolytic reactions [21]. It must be noted that there was recent demonstration of slow digestion of contractile muscular proteins by cathepsin D in the pH range of 6.0 [10].

Rapid restoration of cathepsic activity in red muscles and myocardium after centrifugation and return of animals from the space flight is indicative of the similarity of reactions of these types of muscles, in which there is rather rapid renewal of contractile and regulatory proteins. Hence, proteolytic reactions are a rather sensitive indicator of change in mode of contractile activity of muscles. Apparently, activation of proteolytic enzymes depends primarily on a change in load on the muscle, rather than on change in frequency of contractions. The results of a comparative study of the effects of hypergravity, hypokinesia and a weight load confirm this hypothesis [22]. Proteolytic reactions become rapidly involved in adaptation processes when there is a change in muscular load, and they rapidly regain their initial level after discontinuation of extreme factors. Use of various conditioning loads after prolonged hypokinesia does not elicit the same rapid disappearance of atrophic changes [23, 24].

The obtained data indicate that it is possible to use the level of cathepsic activity as an early indicator of metabolic changes in muscular proteins under the influence of space flight factors.

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CYTOKINETIC EVALUATION OF ERYTHROPOIESIS DURING LONG-TERM ORBITAL FLIGHTS

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[Article by A. V. Ilyukhin and T. Ye. Burkovskaya]

[English abstract from source] The purpose of the investigation was to understand better the mechanisms of erythropoietic changes at the cellular level during a prolonged exposure to weightlessness. Following 96-, 140- and 175-day space flights cytokinetic and morphological changes in erythropoiesis were observed. The count of circulating erythrocytes decreased inflight and their life time reduced postflight. The shortening of the life time of erythrocytes postflight was paralleled by increased proliferative activity of erythroid cells. The erythrocytic balance was not reached as late as R+36. It is recommended that the number of research methods be enlarged.

[Text] At the present time, it may be considered established that man's exposure to weightlessness is associated with redistribution of blood, with some plethora and stasis in the upper parts of the body and parenchymatous organs. Concurrently, one observes an increase in blood concentration due to loss of fluid from plasma. These findings create the false impression of excessive blood in the body. In the opinion of Johnson et al. [1], the observed overfilling of parenchymatous organs, in particular the spleen, prolongs contact between erythrocytes and the hemolytic factor of the spleen, i.e., under such conditions the spleen produces excessive amounts of this factor. As a result of the formed situation, some of the erythrocytes (primarily the least viable ones) perish, and this leads to reduction of erythrocyte mass. These changes also affect renal function. When there is a high blood concentration, making up for the reduction in erythrocyte mass, no hypoxia of renal tissue is observed. On the contrary, there is even some hyperoxia, which leads to decrease in erythropoietin production and corresponding decrease in erythropoietic function of bone marrow. These changes occur against a background of diminished blood requirements of the skeletomuscular system [2]. All this creates a successive chain of cause-and-effect functions that lead to a decrease in proliferative activity of the bone marrow during the adaptation period. Upon termination of the adaptation period, erythropoiesis changes to a different, somewhat lower level of equilibrium, at which the body can exist for an indeterminately long time.

Logically, upon returning to gravity conditions, the mechanisms described for the adaptation period should develop in reverse order, i.e., there should be restoration of normal blood volume leading to decrease in concentration of blood and

this, in turn, elicits some hypoxia, in the presence of which there should be increased production of erythropoietin and more intensive proliferative activity of bone marrow. However, in practice, the mechanism of restoration of normal hemopoiesis is found to be considerably more complex. In this study, we have demonstrated changes om erythropoiesis after termination of 96-, 140- and 175-day flights (orbital missions EO-1, EO-2 and EO-3) and submit data characterizing the distinctions of the mechanisms of normalization of hemopoiesis on the cellular level in the readaptation period. The most distinct changes in erythrokinetics were manifested in EO-3, and the direction of changes was comparable in EO-1 and EO-2. For this reason, it is expedient to combine the results of all three missions.

Methods

To determine the state of erythrocyte balance before flight and at different postflight times, we assayed erythrocytes/μℓ blood, reticulocytes (percentage) before and after 4-h incubation of whole blood in vitro at a temperature of 37°C. We added EDTA as anticoagulant. On the basis of the obtained data, experimental determination was made of half-time (in hours) of reticulocyte maturation ($T_{\frac{1}{2}ret}$) and estimated bone marrow production of erythrocytes (P), i.e., number of cells passing from bone marrow into the blood stream per day, scaled to 1 μℓ blood, as well as half-time of erythrocyte circulation in days ($T_{\frac{1}{2}er}$). To calculate bone marrow production of erythrocytes we used the formula:

$$P = \frac{0.693\ r_0\ N_{er24}}{T_{\frac{1}{2}ret} \cdot 1000}$$

and $T_{\frac{1}{2}}$ of erythrocytes was calculated with the following formula:

$$T_{\frac{1}{2}er} = \frac{0.693\ r_0\ N_{er24}}{P}$$

where r_0 is the number of reticulocytes before incubation and N_{er} is the number of erythrocytes per μℓ blood. We counted the erythrocytes with a cytoscope ["celloscope"?] and reticulocytes on blood smears, counting them per 50,000 or 100,000 erythrocytes with conventional supravital stain with brilliant cresyl blue. The method we used to assess erythrocyte balance is a modification of the method of Ye. N. Mosyagina [3]. It is based on the assumption that equilibrated erythrocyte balance that provides for a constant erythrocyte level in blood is characterized by the same quantity of erythrocytes passing into the blood stream and destroyed within the same period of time. Changes in any element of kinetics (reduction or intensification of proliferative activity, faster or slower differentiation of erythroid precursors, change in life span of erythrocytes, etc.) lead to impairment of the balanced state, which is manifested by a change in erythrocyte count of peripheral blood.

Results and Discussion

At the present time, by combining the results of three long-term flights, we have dynamic data, including the results of base (preflight) tests and those obtained on the 1st, 7th-8th, 27th and 36th days of the readaptation period. However, because of the limited number of tests (sections) and dissimilar number of

experimental points for each of these times, as well as different duration of the orbital flights, we cannot use statistical processing, which no doubt makes it more difficult to interpret the results. Nevertheless, it can be considered firmly established that there was a decrease in quantity of erythrocytes in the blood stream in weightlessness (see Table). This decline was the most distinct 1 week after the flight (by 15-21% of the base levels). Thereafter, the erythrocyte level in blood rose gradually; however, adequate restoration did not occur up to the 36th day. Thus, 27 days after EO-2, the erythrocyte count of peripheral blood constituted 93.8% in the commander (CDR-2) and 83.6% of the base level in the flight engineer (FLE-2), whereas on the 36th day after EO-3 these parameters constituted 85.5 and 88.3%, respectively for the CDR-3 and FLE-3.* The decrease in erythrocytes in peripheral blood was, according to the results of both morphological and cytokinetic studies, associated with development of compensatory processes in the readaptation period, which were manifested by more intensive erythropoiesis. Between the 7th and 27th days, the reticulocyte content of peripheral blood was usually above the top range of the physiological norm, exceeding base levels by 2-4 times.

Erythrokinetic parameters of cosmonauts before and after EO-1, EO-2 and EO-3

Time of study	Subjects	Erythrocyte count		$T_{1/2}$ of erythr.		Bone marrow erythrocyte production		Reticulocytes		$T_{1/2}$ of reticuloc.	
		million per µℓ	%	days	%	thou µℓ/day	%	‰	%	h	%
Preflight	CDR-1	5,20	100	54,1	100	66,5	100	3,8	100	5,0	100
	FLE-1	4,75	100	—	—	—	—	9,0	100	—	—
	CDR-2	4,69	100	32,8	100	99,0	100	8,5	100	6,7	100
	FLE-2	4,57	100	29,8	100	101,0	100	5,5	100	3,9	100
	CDR-3	4,63	100	42,7	100	75,0	100	8,7	100	8,9	100
	FLE-3	4,98	100	—	—	—	—	3,0	100	—	—
Postflight, day: 1	CDR-1	4,53	87,1	19,5	36	154,0	231,6	6,7	176,3	3,2	64
	FLE-1	3,48	73,3	23,6	—	107,0	—	8,7	96,7	4,9	—
	CDR-2	4,60	98,1	53,4	162,8	59,5	60,1	4,3	50,6	5,5	82,1
	FLE-2	4,51	98,7	65,7	220,5	47,6	47,1	3,2	58,2	4,9	125,6
7	CDR-1	4,44	85,4	31,1	57,5	99,3	149,3	16,0	421,1	12,7	254
	FLE-1	3,79	79,8	27,5	—	96,0	—	15,8	175,6	10,4	—
8	CDR-3	3,66	79,0	14,4	33,7	176,0	234,7	24,5	281,6	9,2	103,4
27	CDR-2	4,40	93,8	12,3	37,5	248,0	250,5	17,9	210,6	5,3	79,1
	FLE-2	3,82	83,6	17,0	57,0	209,0	206,9	13,5	245,5	5,5	141,0
36	CDR-3	3,96	85,5	59,0	138,2	40,4	53,9	7,2	82,8	18,0	202,2

The increase in reticulocyte content was associated with concurrent increase in bone marrow erythrocyte production. Thus, medullary production increased to 234.7%, as compared to base levels, on the 8th day of the readaptation period, in CDR-3. Evidently, the period of intensification of erythropoiesis lasts about 1 month. Thus, on the 27th day of the readaptation period, erythrocyte production still constituted 206-250% of base level in both EO-2 cosmonauts.

*V. I. Legen'kov counted the erythrocytes.

With such intensification of erythropoiesis, exceeding the norm by 2-4 times, the demonstrated 20% erythrocyte deficiency in the blood stream but with normal life span thereof should have been eliminated within a period not exceeding 10-15 days. However, the erythrocyte count continued to drop up to the 11th day, and restoration was not observed either on the 27th or 36th day of the readaptation period. On the basis of these data it can be assumed that there is significant reduction of erythrocyte life span in the recovery period. Determination of this parameter confirmed our assumption. The half-time of erythrocyte life span was shortened between the 7th and 27th days after EO-2 and EO-3 (see Table). The reduction was the most marked in CDR-3 (33.7% of base level) and CDR-2 (to 37.5% of base level). After the EO-1, there was less marked shortening of erythrocyte life span.

The last testing time in the readaptation period was 36 days after the EO-3. We have data on kinetics of erythropoiesis only for the CDR-3, who presented a longer life span of erythrocytes at this time ($T\frac{1}{2}$ = 59 days), decreased bone marrow production of erythrocytes (to below base levels) and normalization of reticulocyte content of blood. The erythrocyte count had not yet reached base levels in both cosmonauts and remained in the lower range of the physiological norm. A comparison of the results of studies conducted on the 36th day of the readaptation period to preceding ones creates the impression that intensification of erythropoiesis, which was observed for 27 days, was followed on the 36th day by a change to a lower functional level. The most probable explanation of this effect is the hypothesis that restoration of erythropoiesis, like that of other impaired body functions, occurs in an undulant fashion with gradually regressing amplitude of fluctuations. However, the above data should be considered tentative, since we did not have a sufficient number of cases to derive a completely validated conclusion.

In addition to the above cytokinetic parameters, we also determined the rate of maturation of reticulocytes. We failed to demonstrate substantial changes in rate of differentiation of these cells (see Table). For this reason, it can be assumed that compensatory processes develop essentially due to intensification of proliferative processes and, to a lesser extent, affect differentiation of late stages of precursors of erythrocytes.

When we analyzed the above data, we were impressed by findings indicative of significant (to more than one-half) reduction of erythrocyte half-life in the readaptation period. In this regard, we deem it expedient to dwell in greater detail on analysis of these data. Coordination of dynamics of changes in parameters that are independent of one another (erythrocyte and reticulocyte counts, half-life of erythrocytes) and repetition thereof warrant our excluding the probability of significant methodological errors. In explaning the changes, we must call attention to the similarity of developing compensatory processes to the mechanisms of restoration of erythropoiesis after loss of blood, when the bone marrow produces erythrocytes in an abbreviated variant, i.e., precursors of erytrhocytes undergo no more than 5 divisions, instead of the usual 5-8. There is concurrent acceleration of the cell generation cycle, with utilization of reserve of inefficient erythropoiesis, reduction of time of erythroblast differentiation, etc. The cells thus formed are capable of temporarily compensating for the erythrocyte shortage in the blood stream; however, they are functionally defective and have a shorter life span. The first increase in erythrocyte content of peripheral blood is observed at the expense of short-lived cells and the second, at the expense of erythrocytes that are formed during normalization of erythropoiesis [4, 5]. Perhaps, analogous processes occur in the readaptation period following space flights,

but the inadequate number of studies and forced interruptions in dynamic collection of samples do not enable us to qualify the above assumption more categorically at this time. Yet some caution must be used in drawing an analogy between the mechanisms of restoration of erythrocyte balance after hemorrhaging and effects of space flight factors. We cannot rule out the probability that the reduction of erythrocyte life span in the readaptation period could be the consequence not only of development of compensatory processes, but of deficiency of the erythrocytes that are produced in weightlessness. It is quite likely that the shorter life span of erythrocytes is attributable to summation of both effects.

In our opinion, direct determination of erythrocyte life span, blood and plasma volume (for example, using ^{51}Cr), preflight and postflight examination of bone marrow, comprehensive assay of products of erythrocyte hemolysis, erythropoietin activity, etc., could constitute a rather significant addition to our understanding of the mechanisms of demonstrated changes. However, we do not have absolutely reliable data for the periods with which we are concerned. In view of the foregoing, it can be concluded that there is an obvious need to check the above hypotheses and conduct special investigations in this direction.

Thus, the results of our studies revealed marked changes in erythrocyte balance, which occurred both during exposure of man to weightlessness and in the readaptation period. The obtained data are indicative of a need for further hematological studies in a specific direction and expansion of methodological procedures.

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NOREPINEPHRINE AND ENZYMES OF SYNTHESIS AND DEGRADATION THEREOF IN THE RAT HYPOTHALAMUS FOLLOWING FLIGHT ABOARD THE COSMOS-936 BIOSATELLITE

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 15, No 6, Nov-Dec 81 (manuscript received 7 Aug 80) pp 46-48

[Article by T. Torda, R. Kvetnyanski, R. A. Tigranyan, Yu. Chulman and A. M. Genin]

[English abstract from source] In the hypothalamus of the weightless and centrifuged rats flown for 18.5 days onboard the biosatellite Cosmos-936 the noradrenaline concentration and activity of the enzymes involved in the catecholamine synthesis and degradation were measured. It was found that under the space flight influence the noradrenaline concentration and tyrosine hydroxylase, dopamine-β-hydroxylase and monoamine oxidase activities remained unaltered. These findings indicate that a prolonged exposure to weightlessness was not a stressogenic agent that could activate the adrenergic system in the rat hypothalamus.

[Text] It is known that noradrenergic, dopaminergic, as well as adrenalinergic, neurons of the hypothalamus are involved in regulating many endocrine functions, acting mainly on secretion of releasing hormones. It has been demonstrated that the concentration of catecholamines (CA) in the rat hypothalamus dropped after acute stress [1-3]. Recently, assays were made of CA content of different hypothalamic nuclei and identification was made of the hypothalamic regions showing maximum CA changes in the presence of stress [1, 4, 5]. The decline of CA content of the hypothalamus demonstrable following acute stress was not found in rats exposed to chronic or recurrent stress; in such animals, CA concentration in the hypothalamus did not change due to increased synthesis thereof [1].

Our objective here was to assay norepinephrine (NE) and enzymes of synthesis and breakdown thereof in the rat hypothalamus after a flight aboard Cosmos-936 biosatellite, as well as to compare these data to the results of previous studies, and to assess the stressogenicity of prolonged weightlessness on this basis.

Methods

Studies were conducted on male Wistar-SPF rats (Bratislava, CSSR) flown for 18.5 days aboard the Cosmos-936 biosatellite. Experimental conditions were described by Ye. A. Il'in et al. [6].

After decapitating the animals, we excised the hypothalamus and divided it into two parts. NE content was assayed in the right part [7], dopamine-β-hydroxylase (DBH) [8] and monoamine oxidase (MAO) activity [9] were determined in a homogenate of the left part, while tirosine hydroxylase (TH) activity [8] was measured in the supernatant of the left half of the hypothalamus.

Results and Discussion

It was established that there was a tendency toward decrease in NE concentration in the hypothalamus of both flight groups of rats. A decrease in NE concentration in the hypothalamus was demonstrated in the control group of rats rotated on a short-arm centrifuge (SAC). No changes in NE concentration were demonstrable 25 days after landing (Figure 1).

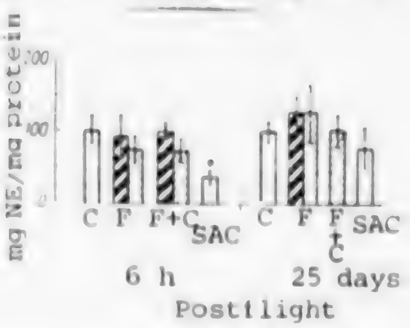

Figure 1.

NE concentration in rat hypothalamus
Here and in Figures 2 and 3:
C) vivarium control
F) flight
F+C) flight in centrifuge
*) reliability of difference ($P<0.05$) from vivarium control
There were 5 animals in each group. Thin-striped columns--flight; thick-striped columns--synchronous experiment

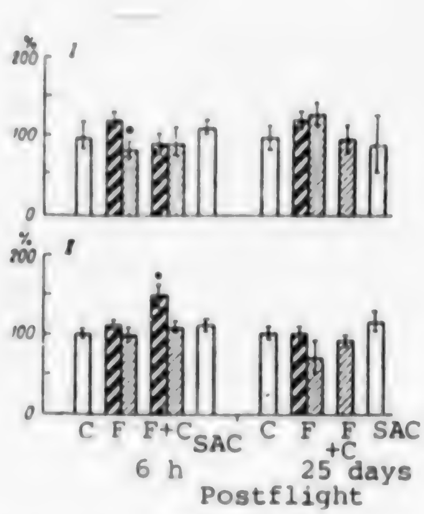

Figure 3.

DBH (I) and MAO (II) activity in rat hypothalamus (% of control). The dot refers to reliability of difference ($P<0.05$) from synchronous control

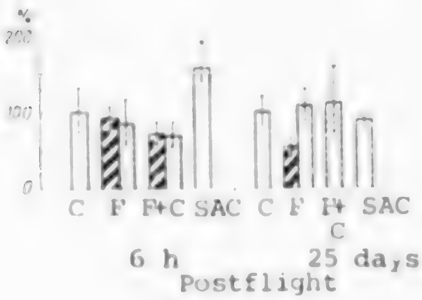

Figure 2.

TH activity in rat hypothalamus (% of control)

In both flight groups there was no change in TH activity, and only elevation of this parameter was noted in the SAC group of animals (Figure 2).

DBH activity remained unchanged in both flight groups of rats both 6 h and 25 days after landing, and it decreased 6 h after landing in rats in the flight group exposed to weightlessness (Figure 3).

MAO activity in the hypothalamus of flight groups of animals did not change at both times tested, as compared to the vivarium control. We only found an increase in activity of this enzyme in rats of the synchronous control group submitted to centrifuging (see Figure 3).

Thus, it was established that the 18.5-day space flight did not elicit changes in concentration of NE in the rat hypothalamus during exposure to both weightlessness and artificial gravity, which was produced aboard Cosmos-936.

It is known that acute intensive stress elicits a decrease in CA concentration of the hypothalamus [1-3], whereas in the case of chronic or periodically recurrent stress there is adaptation of this system and no further decrease in CA content is observed [1]. For this reason, there are two interpretations of the lack of change in NE concentration in the hypothalamus of rats in the flight groups: a) the flight is not a stressogenic factor and b) the animals adapt after an 18.5-day flight and no changes are observed in hypothalamic NE content.

In rats immobilized repeatedly, in whom the NE concentration in the hypothalamus no longer differed from the control rats who were not submitted to stress, there was increase in TH activity, which was indicative of increased CA biosynthesis in the hypothalamus of adapted animals [1]. For this reason, we measured TH and DBH activity in the hypothalamus of flight rats, but no changes in these parameters were demonstrable. These data confirmed the hypothesis that space flights do not constitute an intensive stress factor.

In view of the foregoing, it is interesting to note that only the SAC group of animals presented significant decrease in hypothalamic NE concentration, whereas TH activity increased appreciably. This shows that the adrenergic system of the hypothalamus reacts sensitively to slight hypergravity, to which this group of animals was exposed. Thus, hypergravity can probably be a more intensive stressogenic factor than weightlessness. There was virtually no change in DBH activity; the only exception was the synchronous control group, which showed an appreciable increase in DBH activity, as compared to the flight group. This is a sign of diminished DBH activity in the flight group of rats.

An analogous phenomenon had been observed in rats used in the experiment aboard Cosmos-782 biosatellite [10], which confirms the above hypothesis.

The lack of change in NE concentration in the hypothalamus could also be an indication of altered NE degradation. For this reason, we determined the activity of MAO (a catecholamine-degrading enzyme) in flight rats. We failed to demonstrate any changes in this parameter. This indicates, once more, that weightlessness is not an intensive stressogenic factor.

The submitted results coincide entirely with the findings obtained on rats used in the Cosmos-782, whose hypothalamus also failed to demonstrate changes in either CA concentration or activity of enzymes of degradation thereof [10].

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HYGIENIC PRINCIPLES OF ONGOING MONITORING OF QUALITY OF RECYCLED WATER DURING SPACE FLIGHTS

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 15, No 6, Nov-Dec 81 (manuscript received 2 Feb 81) pp 48-51

[Article by V. M. Skuratov, V. B. Gaydadymov and S. V. Chizhov]

[English abstract from source] The hygienic principles used in the evaluation of the quality of reclaimed water onboard the spacecraft are presented. The parameters required for operational control and their hygienic significance are discussed.

[Text] At the present time, no only hygienists but (though this appears paradoxical) economists too are concerned with the problem of operational monitoring of water quality. Water is among the national resources that primarily limit the economic development of a number of countries. For many years, attention was focused mainly on quantitative evaluation of water, but more recently there has been increased concern about the quality of fresh water, and this resulted in many innovations related to monitoring this parameter. WHO and UNESCO have elaborated a joint project that ultimately provides for global ongoing monitoring of the quality of natural waters [1].

There is the even more acute problem of ongoing monitoring of the quality of water reclaimed from products of vital functions of cosmonauts in the course of long-term missions. In a closed ecological system, the proper quality of potable water is one of the guarantees of health and high work capacity of cosmonauts.

The determination of suitability of regenerated water for drinking purposes during the period of refining the technological mode and resource tests of regeneration systems is based on a set of sanitary and hygienic studies, which include toxicology and analysis of technological efficiency of the system. On the other hand, as shown by our researchers, in the regular regeneration system, which has been tested many times, we can limit ourselves to analysis of only the forms of impurities that are toxic or likely to penetrate into water during operation of the water supply system, as well as production of the system's resource. In other words, one can select a group of criteria that are informative from the sanitary point of view that would guarantee the good quality of water. Such an approach is mandatory for operational monitoring aboard spacecraft where, by virtue of a number of restrictions (weight, dimensions, energy consumption, etc.), water is evaluated on the basis of a minimum number of parameters. Under such conditions, the only acceptable solution is to use integral parameters of water quality, i.e.,

indicators the monitoring of which would yield information about the entire spectrum of possible contaminants. Moreover, in selecting the parameters, one must take into consideration their informativeness, concentration of impurity in the base product for regeneration of water, toxicity of impurities and their ability to penetrate into the regeneration system.

The monitored parameters can be divided into two categories; we can include in the first category the overall rating of water quality, which is used regardless of regeneration method or initial product for obtaining pure water; the second category refers to sampling parameters used in accordance with the distinctions of the water supply system used and initial regeneration product.

Studies pursued by Soviet and foreign authors [2-5] indicate that ongoing evaluation of the quality of water reclaimed from a condensate of atmospheric moisture, urine and "housekeeping" ["sanitary and hygienic"] liquid waste by promising systems of supplying water for spacecraft should be done on the basis of monitoring electric conductivity of water, active pH reaction, levels of organic impurities (overall organic carbon), bacterial contamination, cloudiness, as well as levels of ammonia nitrogen, ionic silver and overall hardness.

Let us discuss the grounds for choosing expressly these parameters.

Electric conductivity of water indicates the levels of organic and inorganic electrolytes in it. Reclaimed water, which has undergone sorption for additional purification, contains virtually no ionized impurities and its electric conductivity is comparable to that of distilled water. An increase in electric conductivity is indicative of impaired function of the sorption filter, i.e., possible worsening of water quality. To improve physiological qualities and organoleptic properties of purified water, it is submitted to artificial mineralization which, of course, elicits a change in electric conductivity that is proportionate to the amount of salts added in treatment of water. For this reason, by placing conductometric sensors at different points of the hydraulic tract of the regeneration system, one can have continuous information about the quality of both purification and conditioning of water.

The reliability and informativeness of conductometry are significantly improved if measurement of electric conductivity is combined with monitoring of an active reaction, i.e., water pH. As we know, the pH is an important indicator of acid-base equilibrium of water.

Organic impurities constitute 60 to 99% of the dry residue of urine and condensate of atmospheric moisture. They contain large amounts of highly toxic and biologically active substances, some of which are volatile, while others are inoxidizable and poorly sorbed. As shown by the results of our studies, the best method is to assess organic impurities according to amount of organic carbon [3]. The most progressive method of assaying organic carbon at the present time is the potentiodynamic monitoring method [6].

Bacterial contamination is a mandatory and most important indicator of quality of potable water. As we know, initial products and water reclaimed from them are markedly infected. Decontamination and preservation will help lower the amount of microorganisms to permissible levels, but only ongoing microbiological monitoring will guarantee the epidemic safety of reclaimed drinking water. The absence

at this time of methods that are suitable for ongoing microbiological monitoring of water during space flights made it necessary to put the rating of ion silver, in which water is preserved, in the second category of parameters [7]. Cloudiness is the only organoleptic indicator that can be monitored with instruments. By virtue of existing conceptions, deterioration of organoleptic properties of water is assessed by man as an indirect indication of appearance of some sort of contaminants in water. What is important is that a change in these properties has a reflex effect on fluid intake and physiological state of the body. Poor organoleptic properties of water elicit a negative physiological reaction, even if one is very thirsty, and it is manifested by refusal to drink or restricting intake of such water [8]. Moreover, it has been established that there is a link between cloudiness and effectiveness of decontaminating potable water, particularly with regard to viruses [9].

Ammonia is included in the list of parameters to be monitored by virtue of its very distinct toxic properties and high concentration in the initial products to be reclaimed (urine, condensate of atmospheric moisture and liquid waste). In addition, ammonia is a volatile compound. Since it is not contained in all base products of regeneration (for example, there is none in the condensate of electrochemical generators), we put this parameter in the second category of criteria of water quality.

As we have already indicated, reclaimed drinking water is submitted to conditioning in the water supply system. In order to assess the quality thereof, we included in the list of parameters the indicator of overall hardness which, as we know, characterizes the levels of calcium and magnesium salts in water. It should be noted that this parameter loses its significance in the case of regeneration of sanitary and hygienic liquids, since the water intended for washing ["water procedures"] is not submitted to conditioning.

The proposed list of parameters that are needed to implement ongoing monitoring makes it possible to assess the quality of reclaimed water aboard spacecraft. Each criterion by itself is an integral indicator of a group of impurities; at the same time they cover the entire range of possible contaminants in water obtained from the onbaord system of water supply.

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TOXICOLOGICAL AND HYGIENIC ASPECTS OF IMPROVING ADDITIONAL PURIFICATION OF WATER RECLAIMED FROM URINE

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 15, No 6, Nov-Dec 81 (manuscript received 2 Feb 81) pp 51-54

[Article by Z. P. Pak, G. V. Lobacheva, M. M. Spiryayeva, Yu. Ye. Bezumova, T. P. Korotkova, V. P. Petina and Ye. S. Yevdokimova]

[English abstract from source] It has been shown experimentally that the quality of reclaimed water as related to its chemical and toxicological parameters depends on the efficiency of the repurification unit. Comparative toxicologic and hygienic investigations have demonstrated that the sorption-catalytic method of urine condensate repurification using a platinum-carbon catalyst is the most promising since it can ensure the production of toxicologically safe potable water.

[Text] Toxicological and hygienic monitoring for detection of the possible presence of trace quantities of preservatives is acquiring even more importance because of the use of highly activated urine preservatives in modern systems.

The question of significance of the additional [final] purification [repurification] stage to obtaining a high grade of potable water is still not entirely clear. The data in the literature deal essentially with the technological aspects of this question, which pertain to increasing the operating resources of the final purification unit [1].

We submit here the results of comparative toxicological and hygienic studies of samples of reclaimed water obtained from urine with the use of different final purification variants.

Methods

Urine to be reclaimed was preserved in chlorine-containing preservative combined with sulfuric acid. Water was regenerated by the method of low-temperature evaporation in a stream of air (SRV-U-NTI).

For final purification of the obtained condensate, we used three variants of charge consisting of activated carbon and ion-exchange resins: sorption charge No 1 (PAU-SV, KU-2-12Pch, AV-17-8Pch), sorption charge No 2 (PAU-SV, KU-23ch, AV-17-10Pch) and sorption-catalytic charge containing a platinum-carbon catalyst (PAU-SV/Rt, KU-23ch, AV-17-10Pch).

Conventional methods of physicochemical and microbiological analysis were used [2] for hygienic tests of recycled water.

The toxicological experiments were conducted on male, mongrel white rats (15 animals per group), kept on a standard diet in the vivarium. Experimental animals were given recycled water in automatic feeders and control rats were given tap water, which was preserved, like the experimental water, in ion silver in a concentration of 0.1 mg/ℓ.

The tests were conducted monthly. Before the experiment, determination was made of background values of parameters. In the course of the experiment, we monitored water intake, dynamics of weight, appearance and behavior of the animals. We examined the morphological composition of peripheral blood: leukocyte content determined in a Goryayev chamber, erythrocytes counted with a photoelectric erythrohemometer, reticulocytes by the method of supravital staining with 1% bright cresyl blue [3]. We tested osmotic [4] and acid [5] resistance of erythrocytes and clotting of whole blood in a Bazaron unit. We determined several biochemical parameters: hemoglobin and methemoglobin content of blood by the spectrophotometric method [6], catalase activity by the method of Bakh and Zubkova [3] and cholinesterase activity in whole blood by the photoelectrocolorimetric method of Hestrin [7], free sulfhydryl group in blood by a modification of the spectrophotometric method of Boyer [8].

Upon terminating the experiment, the animals were decapitated, their internal organs were weighed and weight coefficients thereof were calculated. For pathomorphological examination, the viscera were fixed in formalin, imbedded in paraffin, stained with hematoxylin and eosin, and PAS reaction after Shabadash [9]. The histochemical studies also included assay of glycogen content in the liver in fresh-frozen cryostat sections and lipids using oil red stain [10], lipid content of adrenals stained with sudan black B and ketosteroids with the PAS reaction [9], as well as iron in the spleen by the method of Perls [10].

The experimental data were submitted to processing by the conventional methods of variation statistics for small samples [11].

Results and Discussion

The results of the hygienic studies revealed that the technological system used for preliminary preservation of urine and reclamation of water from it yields a condensate whose quality confirms with GOST specifications for all parameters, with the exception of odor given a grade of 4 points.

The next stage of additional purification of reclaimed water using the three charge variants eliminated the odor, lowered significantly the levels of organic impurities and ammonia nitrogen (see Table).

It is important to note that the level of chemical oxygen consumption dropped to one-quarter and catalytic-sorption consumption to one-eleventh with the use of the variants of sorption charge, which is attributable to destruction on the platinum-carbon catalyst of impurities difficult to sorb that are contained in the condensate, as well as subsequent sorption of products of destruction in the terminal [finish] layers of ion-exchange resins and activated carbon.

Changes in main hygienic parameters of contamination of reclaimed water after additional purification

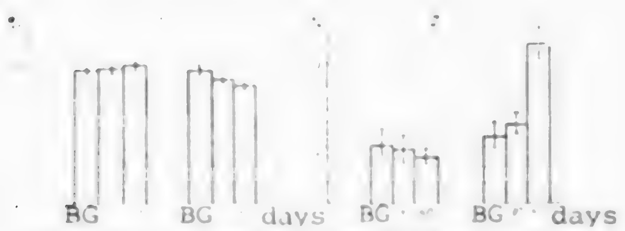
Repurification method	Odor, grade		Chemical oxygen uptake, mg/ℓ		NH_3 content, mg/ℓ	
	condensate	repurified water	condensate	repurified water	condensate	repurified water
Sorption No 1	4	0	80.0	20.0	2.0	0.1
Sorption No 2	4	0	95.0	24.7	1.7	0
Sorption-catalytic	4	0	95.0	8.8	1.7	0

The absence of ammonia in the water after using sorption No 2 and sorption-catalytic methods of additional purification is indicative of a well-balanced composition of the charges with regard to this component of urine.

In the course of operating unit SRV-U-NTI, it was established that the use of these systems increased rather significantly the operating resources of the repurification unit: the amount thereof constituted up to 500 ℓ for sorption No 2 repurification and 1100 ℓ potable water for the sorption-catalytic method.

After the final purification stage, the quality of all three samples of reclaimed water confirmed entirely to the GOST specifications for potable water. However, a comparative toxicological evaluation revealed a number of differences between the samples of water submitted to final purification by the above three variants.

Thus, in the course of the 60-day toxicological experiment with water submitted to additional purification by sorption method No 1, we demonstrated changes in the animals, the nature of which could be indicative of presence in reclaimed water of trace amounts of the preservative, which has oxidative properties, or products of oxidation of organic components of urine.



Dynamics of levels of hemoglobin (I) and methemoglobin (II) in rat blood during 60-day experiment with water reclaimed from urine by sorption method No 1 of final purification [BG--background]

It is known that there is degradation of hemoglobin molecules and increased production of methemoglobin under the influence of oxidants and products of their transformation [12, 13], and this was observed in our studies, as shown in the Figure.

By the 60th day, the experimental group also presented a decrease in osmotic resistance of erythrocytes to 0.677± 0.003% NaCl, which was 17.1% lower than the control level ($P<0.01$). Several authors [14-16] have demonstrated a consistent link between decrease in erythrocyte resistance and increase in methemoglobin content thereof, and this was also observed in our studies. Inactivation of enzymes localized in erythrocytes, due chiefly to oxidation of sulfhydryl groups, was also a probable cause of change

in erythrocyte resistance to hemolysis [17, 18]. From this point of view, there was also conformity of the decline demonstrated in our experiment of level of free SH groups in blood to 67.5 ± 5.3 mg% by the 60th day, which was 19.8% lower than the control level ($P<0.02$).

In addition to the above deviations, we demonstrated changes in histological and morphological structure of the gastrointestinal tract, kidneys and thymus. Small accumulations of protein exudate containing desquamated epithelial cells were found on the surface of the mucosa of the gastrointestinal tract, which could be indicative of signs of gastritis. There was increased cellular mitotic activity in the fimbriate epithelium of the small intestinal mucosa. There is information in the literature concerning impaired mitotic activity of cells in the presence of oxidants [19, 20]. Some edema of tissue, fine vacuolization of cytoplasm of epithelial cells and degenerative changes in nuclei were demonstrated in the cortical layer of the kidneys of experimental animals. The thymus presented an increase in number of plasma cells.

Thus, the demonstrated changes in experimental animals indicate that sorption charge No 1 used for final purification of urine condensate did not remove toxic impurities completely from reclaimed water.

Use of sorption charge No 2, which was modified by addition of new brands of ion-exchange resins, in the repurification unit lowered significantly the adverse effect of reclaimed water on warm-blood animals. In a 180-day toxicological experiment, there were no deviations in histological structure of the internal organs, respiratory function of blood and erythrocyte resistance to hemolysis. However, we demonstrated several deviations of some of the tested parameters.

Thus, erythrocyte content of blood decreased by 8.5 and 10.1% ($P<0.05$), as compared to the control, by the 150th and 180th days, respectively; free SH groups decreased in the blood of experimental rats to 61.9 ± 5.0 mg% by the 150th day; the difference from the control constituted 33.3% ($P<0.01$). By the 180th day, there was incomplete restoration of SH group content of blood (the difference from the control constituted 20.4%, but was not statistically significant, $P>0.05$). In this group of animals, the weight coefficients of the adrenals were 16.4% lower than in the control, with statistical reliability ($P<0.05$).

These deviations are indicative of inadequate effectiveness of the final purification stage with the use of sorption system No 2 to recover safe potable water.

Addition to the charge of platinum-carbon catalyst (sorption-catalytic system) eliminated entirely the adverse effect of reclaimed water on warm-blood animals. The 180-day toxicological experiment failed to demonstrate the deviations that were found when rats consumed water after final purification using sorption methods No 1 and 2. This is apparently related to the more complete breakdown with the catalyst of toxic impurities contained in regenerated water.

Thus, it was experimentally demonstrated that the quality of regenerated potable water depends on effectiveness of the final purification unit, from the standpoint of both sanitary and chemical parameters of the water, and toxicological safety.

The results of the comparative toxicological and hygienic studies revealed that the sorption-catalytic system of final purification of urine condensate is the most

promising, and it provides for sufficient toxicological reliability of recovering regenerated potable water.

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POSSIBLE USE OF HOUSE FLY LARVAE FOR UTILIZATION OF ORGANIC WASTE IN BIOLOGICAL LIFE-SUPPORT SYSTEMS

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 15, No 6, Nov-Dec 81 (manuscript received 28 Jan 81) pp 54-57

[Article by Ye. G. Golubeva and T. V. Yerofeyeva]

[English abstract from source] Musca domestica larvae were grown in organic substrates of three types. The larval density was shown to influence certain parameters characterizing the fly life cycle and the larval utilization of the substrate. The larval development led to a decrease of the substrate mass, humidity and the content of organic matter. Man's native excrements were found to be the best substrate for M. domestica larvae.

[Text] Long-term space flights make it necessary to develop ecological systems with maximally closed cycle of substances, with transformation and utilization of organic waste formed in them. At the present time, the problem of utilizing and transforming waste in biological life-support systems is being solved mainly by two methods--physicochemical and biological. With regard to the biological method, it is interesting to explore the possibility of using insects, in particular synanthropic flies that are very fertile, have a relatively short life cycle and can develop in a wide diversity of organic substrates for the purpose of utilizing waste.

Our objective here was to test the effect of density of house fly (Musca domestica L.) larval population in a substrate on some biological parameters characterizing its life cycle and degree of utilization by the larvae of some organic substrates in a biological system of human life support (BLSS).

Methods

The larvae were placed in unadulterated and bacterially mineralized human excreta, as well as droppings of the Japanese quail (heterotrophic element of future BLSS for man). The population density of larvae placed in the substrate was expressed as number of larvae per gram substrate (1/g). Several densities were tested for each substrate (Table 1).

We evaluated the effect of larval density on the fly's life cycle on the basis of mean weight of pupae, total biomass of pupae and prepupae, larval death in the course of development (percentage), hatching of adult flies from pupae (percentage),

duration of development to pupal stage (days), duration of pupation period (days), period between end of pupation to start of hatching (days) and hatching period (days).

In evaluating substrate processing by the larvae, we considered the following parameters: crude mass yield (ratio of larval biomass obtained to substrate processed by larvae, percentage); crude mass and substrate moisture before and after development of larvae in it; amount of organic substrate matter processed by larvae (percentage of initial amount, according to ash content).

The larvae were obtained from females of the 4th-5th laboratory generation. Jars made of polystyrene, with 250 cc capacity, were used for raising the larvae. In each of them 50 g substrate was placed. Experiments using each larval density were repeated 3-5 times at a temperature of 25±1°C and relative humidity of 55-60%.

The criteria of Student for small samples were used to assess the reliability of the quantitative results.

Results and Discussion

There was decrease in mean pupal mass with increase in density for all substrates. However, the nature of decrease in average pupal mass was not the same with different substrates. Thus, for human excreta, there was gradual decrease in mean pupal mass with increase in density of larval population (see Figure 1). At low densities (1-4 l/g), there were no reliable differences in values of this parameter. Further increase in larval population density led to gradual and reliable decrease in weight of the pupae, to virtually the maximum of 8 mg (when the weight of prepupae drops to 6-7 mg pupation does not usually occur [1]).

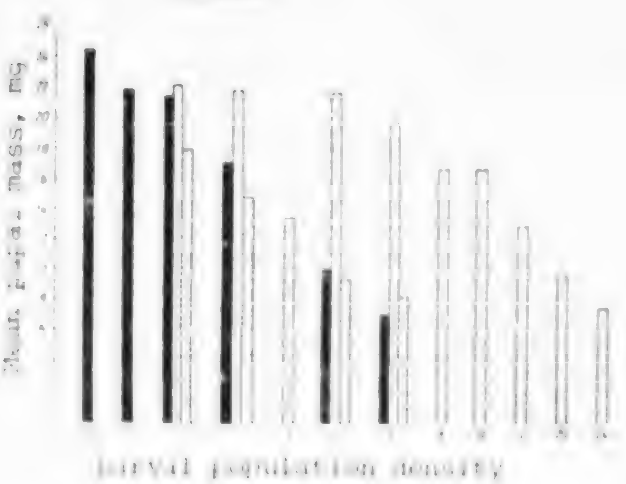

Figure 1.
Mean weight of pupae as a function of density of substrate population (crude weight)

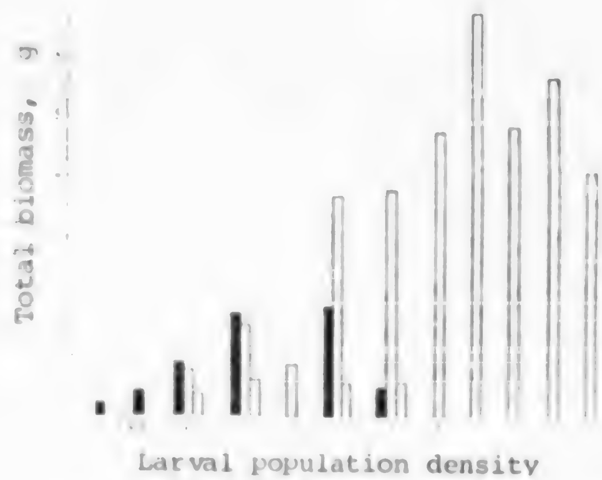

Figure 2.
Overall biomass of pupae and prepupae as a function of density of substrate population (crude weight)

In Figures 1, 2 and 4: black columns--Japanese quail droppings; white--unadulterated human excreta; cross-hatched--mineralized human excreta.

Table 1. Density of population of house fly larvae used in experiments

Type of substrate	Larval density, 1/g
Unadulterated human excreta	1, 2, 4, 6, 8, 10, 12, 20, 24
Mineralized human excreta	1, 2, 3, 4, 6
Japanese quail droppings	0.2, 0.5, 1, 1.5, 2, 4, 6

When the larvae developed in Japanese quail droppings and mineralized human excreta the mean pupal mass (starting with a density of 1 1/g) dropped drastically for each subsequent density (see Figure 1), and densities of 1-4 1/g, which are low for human excreta, were found to be high for these substrates, whereas 6 1/g was the maximum.

At first there was an increase in overall pupal and prepupal biomass for all substrates with increase in density of larvae; then, after reaching a maximum (see Figure 2), it decreased. The same tendency of change in overall biomass and mean weight of pupae as a function of larval density was noted when they developed in beef liver [1].

The maximum total biomass was lowest when the larvae developed in mineralized human excrements. It was twice this level for Japanese quail droppings and almost 9 times more for unadulterated human excreta than for mineralized human excreta. With low densities, the biomass consisted only of pupae and with high densities it consisted of pupae and prepupae. This is related to the fact that, with high densities, some of the prepupae do not reach a sufficient weight for pupation, and with increase in density of larvae there is increase in number of prepupae that do not undergo pupation, whereas their mass drops (Table 2).

Table 2. Mean mass and share of total biomass referable to unpupated prepupae as related to different population densities

Substrate	Substrate population density, %	Unpupated prepupae, %	Mean mass of unpupated prepupae, mg
Unadulterated human excreta	12	22.5	3.9
	20	33.1	3.8
	24	42.7	3.4
Mineralized human excreta	1	7.1	5.2
	4	55.5	4.5
	6	65.6	3.8
Japanese quail droppings	6	94.1	3.6

The percentage of larval deaths during development and percentage of hatching of adult flies from pupae did not depend reliably on population density and ranged from 15 to 32 and from 74 to 92, respectively.

Duration of development was unrelated to substrate population density and constituted a mean of 7 days; prepupae appeared on the 5th-6th day of development. The

periods of pupation and hatching of flies increased from 3 to 6 and from 4 to 8 days, respectively, with increase in density. Conversely, the period between end of pupation to start of hatching shortened (from 4 to 1 day) with increase in population density in the substrate.

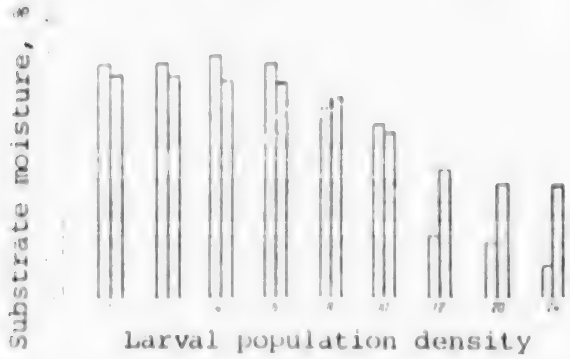

Figure 3.
Moisture content of unadulterated excreta as a function of substrate larval density. White columns--experiment, cross-hatched--control (without larvae)

The overall biomass yield (percentage of substrate mass) first increased with increase in density of larvae, then decreased. Maximum biomass yield constituted 7.3% with Japanese quail droppings, 20% with mineralized human excreta and 53.3% with unadulterated excreta with densities of 4, 3 and 20 1/g, respectively.

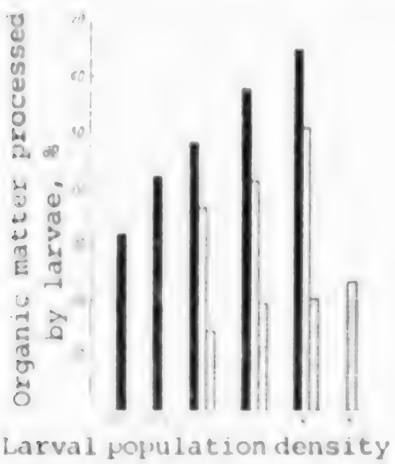

Figure 4.
Effect of larval density in substrate on amount of organic matter broken down during larval development

During development of larvae in the substrate its mass diminished by a mean of 50-60%.

The change in moisture content of the substrate as a function of larval density (for human excrements) is illustrated in Figure 3.

With low densities, the moisture content of substrate processed by the larvae exceeded control levels; with increase in larval density it decreased (to a maximum of 20%, as compared to the control). Such change in moisture content is apparently related to the fact that with low densities the larvae, which excrete a significant amount of digestive enzymes [2], do not mix the substrate well. At higher densities, there is marked evaporation of moisture, probably because the larvae raise substrate temperature during development by several degrees [2-4] and mix it actively.

The amount of organic substrate matter decomposed by larvae during development increased with increase in population density (Figure 4).

When the larvae developed in Japanese quail droppings, they digested up to 65% of the organic substrate matter. Apparently, this is attributable to the fact that when the substrate is left standing it is markedly decomposed (loss of organic matter in the control constituted up to 30%). For unadulterated and mineralized human excreta, loss of organic substrate matter while left to stand constituted a mean of 10 and 7%, respectively, in the control.

During development on mineralized human excreta, the larvae decomposed a maximum of 23% of the organic matter in the substrate.

Thus, there is reduction of mass and moisture of the substrate as a result of larval development, as well as decrease in organic matter it contains.

A comparison of the substrates used for larval development shows that unadulterated human excreta are the best substrate for development.

Considering the effect of density on the parameters studied, one can select a range of larval densities of interest to future studies. It constitutes 6 to 12 l/g for unadulterated human excreta, 1-3 l/g for mineralized human excreta and Japanese quail droppings.

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DISTINCTIONS OF REGENERATION OF CONFINED ATMOSPHERE BY MEANS OF PHOTOSYNTHESIS OF UNICELLULAR ALGAE

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 15, No 6, Nov-Dec 81 (manuscript received 22 Oct 80) pp 58-62

[Article by G. I. Meleshko, L. M. Krasotchenko and Ye. K. Lebedeva]

[English abstract from source] Systems of biological air regeneration using photosynthesis of unicellular algae shown an oxygen-carbon dioxide mismatch associated with the difference in gas exchange coefficients of man and algae. The value and vector of the mismatcn depend on the degree of the above difference. In the system balanced with respect to oxygen consumption and carbon dioxide production, the rate of the mismatch equals to 1 per cent of either process per each unit of the difference of the gas exchange coefficients in the second decimal point. The paper presents methods for regulating the algal assimilation coefficient based on the use of various nitrogen forms for algal nutrition and controlled biosynthesis. The paper also describes optimal variants of gas exchange balance in the semi-closed biological life support systems.

[Text] A model of a biological life-support system for man, based on the interrelationship between man, unicellular algae and concomitant microflora, has now been developed. In spite of the simplicity of biocenotic structure, a high percentage of reclamation of substances has been obtained in such a model. It provides 100% of man's oxygen and water requirements without a reserve thereof; it removes 90% of the carbon dioxide discharged by man; it reproduces 8-10% of the nutrients and removes water-soluble gaseous impurities from the atmosphere [1, 2]. An efficient technology has been developed for such systems with regard to waste-free cultivation of unicellular algae [3], and it was demonstrated that they are highly reliable, due to the wide range of adaptability of algae and concomitant microflora. Exogenous mineral salts are placed in the system to feed algae and sublimated products of man's diet, whereas the incompletely utilized algal biomass and solid human waste are removed from the system after drying.

This model is promising for use in proposed bioregenerative systems; however, it must be borne in mind that it does not naturally provide for a physical balance. This is related to the difference in composition of elements of substances entering and exiting from the system, and pertains primarily to the flow of main elements--oxygen, carbon, hydrogen and nitrogen. Impairment of the oxygen and carbon

dioxide balance in the atmosphere of a closed system, which leads to instability thereof, is one of the manifestations of this disparity.

Carbon dioxide uptake and oxygen output during photosynthesis by unicellular algae makes it possible to satisfy the gas exchange needs of any organism with the heterotrophic type of metabolism, including man. However, the very first experiments dealing with conjugate gas exchange of algae and heterotrophic organisms (mice, rats, dogs, monkeys) revealed that there is impairment of oxygen and carbon dioxide balance in the atmosphere of a closed system [4, 5]. These data have been confirmed by us [6-8] and other authors [9] in experiments, where human gas exchange was provided by photosynthesis of chlorella. Impairment of the oxygen and carbon dioxide balance in the atmosphere of a closed system is related to disparity between the assimilation coefficient (K_{ass}) of algae ($O_2:CO_2$) and the respiratory coefficient (K_{res}) of man ($CO_2:O_2$). For the sake of convenience in comparing these parameters, we shall discuss the assimilation coefficient of algae in the form of its reciprocal, as the ratio of volumes of absorbed carbon dioxide to discharged oxygen ($CO_2:O_2$), as it is customary to express the respiratory quotient.

Studies of the photosynthetic [assimilation] coefficient of chlorella revealed that, depending on the nitrogen source in the medium, it may be either lower (0.76-0.78) or higher (0.90-1.00) than the respiratory quotient of man [4, 6, 7, 10]. The human respiratory quotient is in the range of 0.84-0.86, and it is a rather stable parameter with a standard diet [11].

For a long period of time, in developing the photoautotrophic element on the basis of algae, as well as developing and studying the most elementary models of biological life support systems (BLSS) for man based on such an element, we studied the levels and direction of disparity of the carbon dioxide and oxygen balance in the atmosphere of a closed system, and we explored the means of balancing these gases in autotrophic-heterotrophic systems.

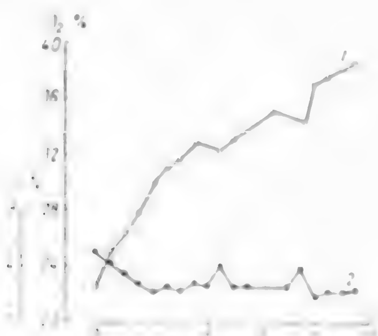
Methods

The studies were conducted in "chlorella-animal," "chlorella-man" systems with closed gas exchange and in a "man-chlorella-mineralization" system closed for gas exchange, water, partially for food and biogenous elements. Chlorella was cultivated in a continuous stationary mode [without flow] using balanced nutrient media [12, 13]. Potassium nitrate, ammonia nitrate and human urine urea were used as nitrogen sources. The algae were cultivated in rotation and bubbling types of photosynthetic reactors with suspension in a volume of 3 and 15 ℓ, respectively. The reactors were connected to pressurized chambers for man or animals.

The studies involved some problems from the very start due to the fact that impairment of carbon dioxide and oxygen balance in the system's atmosphere elicited disparity, not only of gas exchange coefficients, but overall levels of human and algal exchange of gases, for which reason the dynamics of disruption of balance were rather complicated [7]. For this reason, before we undertook the study of actual levels of impairment of gas balance in the atmosphere due to disparity of gas exchange coefficients and searching for means of eliminating it, we explored the possibility of controlling the algal element. As a result, we developed a relay method of controlling productivity of the algal element, which enabled us to stabilize the concentration of one of the gases in the atmosphere (carbon dioxide or oxygen) within the specified range [14, 15].

Results and Discussion

These studies established that the magnitude and direction of impairment of carbon dioxide and oxygen balance in the atmosphere depend on the difference in gas exchange coefficients and the parameter (oxygen or carbon dioxide) according to which gas exchange in the system is balanced. In all of the studies, the findings were the same: when the elements were balanced for oxygen, carbon dioxide either accumulated in the atmosphere with elevation of overall pressure (when the photosynthetic coefficient was lower than the respiratory quotient) or diminished with decline of overall pressure in the system (when the assimilation coefficient was higher than the respiratory quotient). When gas exchange was balanced in the system for carbon dioxide, the same findings were observed with respect to oxygen. The absolute magnitude of change in balance was greater than in the former case. Figure 1 illustrates the dynamics of concentration of oxygen [1] and carbon dioxide [2] in the atmosphere of a "chlorella-animal" system with balanced exchange of gases for carbon dioxide by controlling productivity of the algal element. In this case, there was accumulation of oxygen in the atmosphere.



Time, days

Figure 1.
Dynamics of concentration of oxygen (1) and carbon dioxide (2) in the atmosphere of a chlorella-animal system that is closed for exchange of gases

The data obtained in autotroph-heterotroph systems closed for gas exchange and calculations made on this basis revealed that a 1% discrepancy between gas exchange coefficients of the autotrophic and heterotrophic elements in a system balanced for oxygen or carbon dioxide leads to accumulation or loss of 1% of the oxygen used in the system or carbon dioxide put out by it.

Thus, it was established that to stabilize both oxygen and carbon dioxide simultaneously in the atmosphere of a closed system, it is necessary to control not only productivity of the algae, but gas exchange coefficient of at least one of the elements of the system.

We tested and analyzed the methods proposed in the literature for regulating gas exchange coefficients of algae and man in order to balance oxygen and carbon dioxide in the atmosphere of a closed system. One of the methods we previously proposed involved regulation of algal K_{ass} by means of two forms of nitrogen in the nutrient medium--nitrates and urea [7]. It was estimated that about 30% of the algal suspension (in relation to total amount) must be cultivated on a nutrient medium containing urea as the source of nitrogen in order to obtain an algal K_{ass} equal to the respiratory quotient of man. It is assumed that this amount of urea can be provided by human urine.

To use this method of controlling algal K_{ass}, we developed a special technology for using two forms of nitrogen (nitrates and urea) concurrently in a continuous stationary culture, which made it possible to raise the K_{ass} of algae raised autonomically from 0.76-0.78 to 0.82-0.83 and, consequently, bring it closer to man's respiratory quotient. However, when tested under the actual conditions of a closed system with man, this control method was found to be ineffective. Under

these conditions, the disparity between gas exchange coefficients and, consequently, degree of impairment of gas balance in the system remained just the same as when only nitrates were used in the nutrient medium for algae (see Table, Nos 2-4). The degree and structure of impairment of gas balance differed somewhat for the analyzed results. In studies Nos 2 and 4, gas exchange in the system was balanced for both oxygen and carbon dioxide; for this reason, there was first accumulation of carbon dioxide in the system and then of oxygen. In study No 3, gas exchange was balanced for oxygen and the impairment of balance was manifested by accumulation of carbon dioxide in the system's atmosphere.

Impairment of oxygen and carbon dioxide balance in the atmosphere of man-chlorella and man-chlorella-mineralization systems as related to different forms of nitrogen nutrition of unicellular algae

Study No	Duration of study, days	Source of nitrogen in medium	Impairment of balance, %		
			CO_2	O_2	$CO_2 + O_2$ from discharged CO_2
1	14	Nitrates	+5.0	+0.2	+6.5
2	31	Nitrates + urea	+3.0	+1.7	+5.2
3	29	Same	+6.4	+0.4	+6.9
4	12	"	+1.8	+3.3	+5.5
5	15	"			
		Nitrogen shortage in medium	+2.0	+0.6	+3.2

Analysis of the results revealed that, in spite of the opinion formed in the literature, use of urea in the algal nutrient medium in a closed chlorella-heterotrophic organism system leads to the opposite effect--an increase in gas exchange coefficient of oxygen uptaking elements due to discharge of an additional amount of carbon dioxide as a result of breakdown of urea. The amount of additional carbon dioxide with the use of urine from one man constituted 3-4% of that put out in the course of breathing, and accordingly it altered the overall coefficient of carbon dioxide "outputting" elements. At the same time, when algae were cultivated in a self-contained mode with the use of urea, the emitted carbon dioxide is inevitably taken into consideration in gas exchange of algae, and this is what causes the apparent elevation of the photosynthetic coefficient. This is related to the fact that the difference in algal K_{ass} as a function of nitrogen source in the medium is attributable more to the additional amount of oxygen (in the case of nitrates) or carbon dioxide (in the case of urea) with mineral salts, which are considered in measuring algal gas exchange, than to the direction of metabolism.

Thus, our attempt at balancing gas exchange in a real man-algae closed system by using various forms of algae for nutrition of algae did not yield the desired results and, as we learned, signified nothing other than putting in the system an additional amount of carbon dioxide or oxygen as part of the stock of salts. The attempt made by other researchers [16] to control man's respiratory quotient by altering his diet (increasing carbohydrate content) amounted to the same result. In this case, the corrective stock of oxygen was transferred to man's diet. Consequently, using the above methods of controlling human and algal gas exchange coefficients is associated with an increase in stock of substances and does not really solve the problem.

It became obvious from our studies that one can avoid disruption of the gas balance only if there is equality between the composition of biomass synthesized by algae and assimilated part of man's diet. To achieve this, we made use of the algal property of selectively altering the composition of biomass [17]. A positive effect was obtained when selective biosynthesis was used to control the K_{ass} of algae. For this purpose, we developed the technology for continuous cultivation of algae with selective biosynthesis and selected the most effective controlling parameter--shortage of nitrogen in cells, and examined the K_{ass} of algae as a function of this parameter. It was established that, concurrently with decrease in supply of nitrogen for cells, there is a change in composition of biomass and value of K_{ass}. As the shortage of nitrogen in cells increased, the photosynthetic coefficient passed through the maximum (0.90-0.93) when there was 35-40% less than nominal N level in the cells (Figure 2). With further reduction of delivery of nitrogen to cells, K_{ass} decreased and reached the base value when there was 50% less than normal nitrogen content in cells. This is attributable to the fact that reduction of organic cellular matter does not change proportionately to the severity of nitrogen deficiency.

The above method of controlling algal K_{ass} was used in one of our studies (see Table, No 5) of a model of a human BLSS, in which 30% of the algal suspension was cultivated with limited nitrogen. Nitrogen supply of cells constituted about 70% of their requirement. As a result, there was a change in biomass composition and increase of K_{ass} which, in turn, had a beneficial effect on gas balance in the atmosphere. Impairment of gas balance decreased to almost one-half the extent observed in the preceding studies, where the same system structure was used. The amount of suspension cultivated with a shortage of nitrogen must be increased by about two times for there to be a complete balance of gases. These are only preliminary data, but they show that there is a realistic possibility of controlling gas exchange in the system by means of the algal element. In view of the fact that use of this method is associated with a decrease in productivity of algal cultures and, at the present time, involves difficulties related to ongoing control of nitrogen content of cells, we concluded that it is hardly expedient to use it in systems with such simple biocenotic structure.

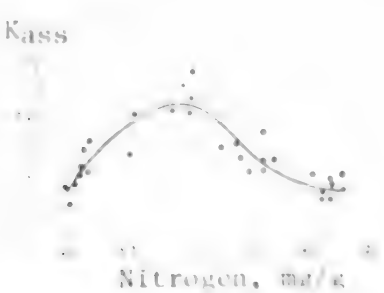


Figure 2.
Value of photosynthetic coefficient of chlorella as a function of amount of nitrogen in the cells

When developing and operating such systems, one should proceed from the fact that they function with inevitable impairment of gas balance. For this reason, we developed a method of maintaining gas equilibrium by means of periodic removal of excessive carbon dioxide from the system with stabilization of oxygen in the atmosphere. When using this method, the algal K_{ass} must be lower than man's respiratory quotient (or that of another heterotrophic element). The most suitable form of nitrogen for cultivating algae is ammonia nitrate, which contains enough oxygen to assure a low algal K_{ass}. At the same time, it is possible to use the nitrogen of human urine in the form of ammonia [18]. With this method of stabilizing gas exchange in our experiments, accumulation of excessive carbon dioxide constituted 5-6% of the rate of its output by man. Absorption of such an

excess of carbon dioxide by regenerated absorbers presents no difficulties whatsoever, as compared to absorption of excessive oxygen when gas exchange in the system is balanced for carbon dioxide. We used this method of balancing gases in the system in a study of models of human BLSS based on photosynthesis of unicellular algae, and it proved itself well. Figure 3 illustrates the dynamics of oxygen and carbon dioxide concentration in one of the tests. The oxygen concentration in the atmosphere was maintained at a level of 22-23% and that of carbon dioxide was in the range of 1.0-3.5%. Upon reaching the top value, carbon dioxide was absorbed by a chemical absorbent. Evidently, the problem of balancing gas exchange coefficients of algae and man can be eliminated from such systems.

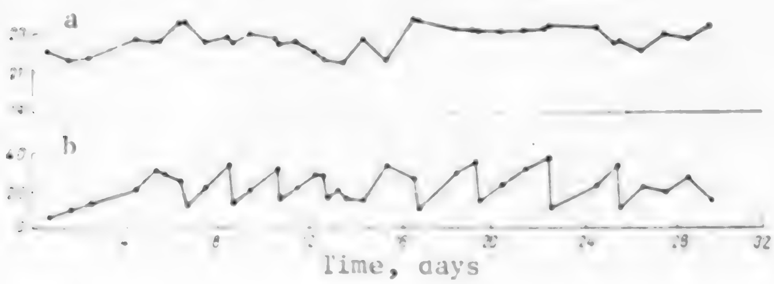


Figure 3. Dynamics of concentration of oxygen (a) and carbon dioxide (b) in atmosphere of man-unicellular algae-mineralization system closed for gas exchange and water

In more complex systems, the degree of impairment of gas balance in the atmosphere related to disparity of gas exchange coefficients will diminish spontaneously with increase in species diversity and closed state of trophic links in them.

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UDC: 612.014.47

PHENOMENA OF FLUCTUATION OF HUMAN REACTION TO ANTIORTHOSTATIC POSITION

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 15, No 6, Nov-Dec 81 (manuscript received 22 Dec 80) pp 63-65

[Article by L. Lkhagva (Mongolian People's Republic)]

[English abstract from source] The biorhythmological analysis of the data obtained from 7 healthy male test subjects in the head-down position at -8° revealed phenomena of sine-shaped reactions. This pattern was seen in the range (the difference between mean day-time and mean night-time values) of heart rate, amplitude (the difference between the maximum and minimum) of variations of body temperature and renal potassium excretion, and the evening-morning difference of body temperature variations.

[Text] Fluctuation of reactions of animals and man to the most diverse stressors has been reported [1-4]. Our objective here was to demonstrate fluctuations of human reactions to antiorthostatic positions.

Methods

We conducted two series of studies with the participation of 7 healthy male subjects 23-33 years of age who resided permanently at moderate altitudes. The studies were conducted in November-December (first series) and January-February (second series).

The subjects maintained bed rest in antiorthostatic [head down] position (-8° tilt angle) for 7 (first series) and 12 (second series) days. We examined their circadian rhythms of body temperature, heart rate (HR) and excretion of potassium in urine.

Body temperature was measured under the tongue with a medical mercury thermometer (0.1°C scale graduations). Temperature was taken during the waking period, from 0700 to 2300 hours, at 2-h intervals (i.e., at odd-numbered hours) and once during sleep (at 0300 hours). HR was determined by palpation of the right radial artery for 1 min. The recording time was synchronous with measurement of body temperature. Potassium excretion in urine was assayed every 4 h with a flame photometer. In the background period, the parameters were recorded for 5 (first series) and 12 (second series) days, and for 8 days in the readaptation period (both series). The subjects had a less restricted motor regimen at the latter time.

In the course of our biorhythmological analysis of the data, we concentrated mainly on the differences in recorded parameters, in particular the HR range (difference between mean daytime and mean nighttime levels), amplitude (difference between maximum and minimum levels) of body temperature, excretion of potassium in urine in the evening (2300 hours) and morning (0700 hours). For each day, we calculated the differences in the above-mentioned parameters and averaged them for test periods.

Results and Discussion

The results of this study revealed that, due to a decline of mean daytime levels in antiorthostatic position, the range of daily fluctuations of HR diminished, as compared to the background period (Table 1). In two subjects (Nos 1 and 2), although this parameter did increase in the readaptation period, as compared to the head-down period, it did not reach the base level and exceeded the background level in only one subject (No 3).

Table 1.
Range of daily HR (per min) fluctuations

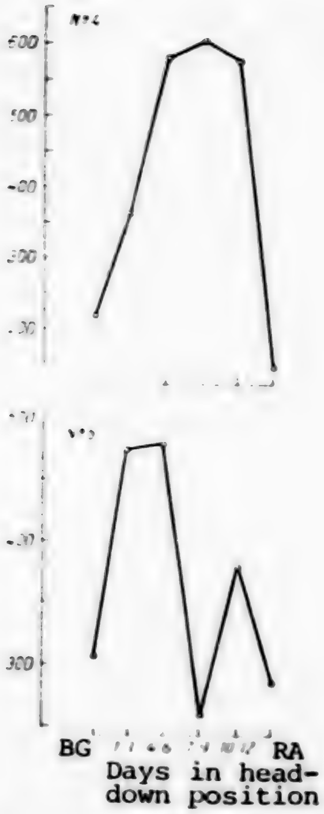
Period	Subject No		
	1	2	3
Background	13,06	9,10	10,33
Head down, days:			
1-3	6,46	3,84	7,01
4-7	9,64	5,64	7,67
Readaptation	8,13	8,37	11,35

Table 2.
Amplitude of daily body temp. rhythm (°C)

Period	Subject No			
	4	5	6	7
Background	0,78	0,94	1,01	0,81
Head down, days:				
1-3	0,57	0,74	0,80	0,54
4-6	0,90	1,10	0,96	0,84
7-9	0,73	0,81	0,87	0,83
10-12	0,87	1,03	0,93	0,87
Readaptation	0,76	1,07	0,95	0,88

Elevation of body temperature at the stage of its daily minimum for the first 3 days of head-down position led to a reduction in amplitude of daily temperature rhythm in this period (Table 2). For the next 3 days, all subjects presented an increase in amplitude of daily fluctuation of body temperature, as compared to the figures obtained on the 1st-3d days of antiorthostatic position, and 3 of them (Nos 4, 5 and 7) presented a higher amplitude on the 4th-6th day of head-down position than the initial level (see Figure). In 2 of these subjects (Nos 4 and 5), the amplitude decreased again on the 7th-9th days of antiorthostatic position to below the base level, then again increased to above base levels (see Figure). Consequently, the dynamics of amplitude of daily fluctuations of body temperature of these subjects presented marked fluctuations during the antiorthostatic test. During the period of these tests, there was fluctuation of amplitude of temperature in one subject, which remained below the base level; in the other one, after an initial decline and subsequent elevation in relation to the base level, it remained above the background level to the end of this period.

Analysis of the difference between evening (2300 hours) and morning (0700 hours) temperatures also revealed fluctuating dynamics of this parameter, which was particularly evident in 3 subjects (Table). On the 1st-3d days of antiorthostatic position, the difference between evening and morning temperature of one subject was below the background level, but above it thereafter (including the readaptation period).



Numerical values of amplitude of circadian rhythm of excretion of potassium in urine in subjects Nos 4 and 5 at different stages of the study. X-axis, period of study (days); y-axis, potassium excretion (mg/4 h)
Key: BG) background
RA) readaptation

Table 3.
Difference between evening (2300 hours) and morning (0700 hours) body temperatures (°C)

Period	Subject No			
	4	5	6	7
Background	0,20	0,20	0,48	0,33
Head down, days:				
Head down, days:				
1-3	0,20	0,23	0,43	0,16
4-6	0,30	0,30	0,53	0,50
7-9	0,27	0,13	0,73	0,70
10-12	0,10	0,33	0,60	0,67
Readaptation	0,11	0,57	0,60	0,43

On the 1st-6th day of the test, subject No 5 presented an increase in difference between evening and morning body temperatures; it decreased to less than background values on the 7th-9th days, whereas it increased significantly on the last 3 days of head-down position, as compared to the background value. In subject No 4, there was no change in difference between evening and morning body temperature for the first 3 days of antiorthostatic position; it increased in comparison to the background on the 4th-9th days, then decreased to below background values on the 10th-12th day of head-down position and readaptation period.

Throughout the period of antiorthostatic position, the amplitude of circadian rhythm of potassium excretion in urine (see Figure) exceeded background levels in subject No 1, whereas in subject No 5 it was sometimes above and sometimes below (7th-9th days) background levels.

In the readaptation period, all subjects presented numerical values of amplitude of circadian rhythm of potassium excretion in urine that were below the background levels.

A comprehensive analysis of data in the literature pertaining to the dynamics of the body's responses to stress factors revealed that the fluctuating phenomena we demonstrated are not attributable to chance. Fluctuation is a nonspecific reaction to stressors, i.e., it characterizes the course of an adaptation process in its general manifestations. Jurgensen (quoted in [5]), who analyzed the causes of this phenomenon, wrote that there is a certain "law of compensation," according to which a deviation of some function elicited by some factor is necessarily

compensated by a deviation in the opposite direction, for which reason the mean parameters characterizing the function remain unchanged.

Expressly the contradictory nature of adaptive reactions is the source of their fluctuating course.

According to the foregoing, when studying the body's responses to some factor, one cannot pose the question in the form of "What is the reaction to this factor?" The question must be formulated differently: "What is the reaction to this factor at a specific time," since the reaction may not only be quantitatively different at different times after exposure to the factor, but could be opposite in sign.

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RESULTS OF STUDY OF HEMODYNAMICS AND PHASE STRUCTURE OF THE CARDIAC CYCLE DURING FUNCTIONAL TEST WITH LOWER BODY NEGATIVE PRESSURE DURING 140-DAY SALYUT-6 STATION FLIGHT

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 15, No 6, Nov-Dec 81 (manuscript received 19 Jun 80) pp 65-69

[Article by A. D. Yegorov, O. G. Itsekhovskiy, I. I. Kas'yan, A. P. Polyakova, V. F. Turchaninova, I. V. Alferova, V. G. Savel'yeva, M. V. Domracheva, V. G. Doroshev, Ye. A. Kobzev, A. S. Barer and Ye. P. Tikhomirov]

[English abstract from source] The two members of the 140-day permanent Salyut-6 space flight were exposed to 5 LBNP tests at -25 and -35 mm Hg for 2 and 3 min, respectively. Circulation responses to the LBNP tests were measured with respect to the heart rate, arterial pressure, chronocardiogram and cardiac output. As compared to the preflight data, inflight responses were characterized by a greater tachycardia, preload insufficiency, and vascular tone in the absence of orthostatic intolerance. Possible mechanisms of the changes in the circulation responses are discussed.

[Text] During space flights, much attention is devoted to changes in orthostatic stability, since this parameter reflects, to a significant degree, deconditioning of the cardiovascular system with regard to gravity loads. Intensification of reactions to orthostatic tests and lower body negative pressure (LBNP) were noted in cosmonauts after most space flights, regardless of their duration [1], as well as during the missions aboard Salyut [2] and Skylab [3] orbital stations.

We studied here the distinctions of cardiovascular reactions to LBNP during a 140-day space flight.

Methods

We conducted 4 tests in the preflight period and 5 in flight, on the 7th, 50th, 85th, 124th and 137 days, on cosmonauts who were members of the main crew.

LBNP was created by means of wearing pneumovacuum gear on the lower half of the body, which was sealed on the level of the iliac crests. Rarefaction modes constituted 25 mm Hg for 2 min and 35 mm Hg for 3 min. During the sessions of telemetric communication, the following parameters were recorded: pressure in the pneumovacuum gear, kinetocardiogram from the region of the apex beat, tacho-oscillogram of the brachial artery, pressure in the compression cuff, sphygmogram

of the femoral artery (in the region of the upper third of the thigh), rheoencephalogram of the right and left cerebral hemispheres. Processing of the obtained data included the following: determination of heart rate (HR), stroke (SV) and minute (MV) volumes of circulation, minimum (AP_d), mean (AP_m), lateral (AP_l), end (AP_e) and pulse (AP_p) arterial pressure, pulse wave propagation velocity in the aorta ($PWPV_a$), duration of phase of isometric contraction (IC), period of ejection of blood by left ventricle (EP), IC/EP ratio, actual (SPR_a) and nominal (SPR_n) specific peripheral resistance, as well as rheoencephalographic parameters characterizing filling (ratio between variable and constant components of impedance) and tonus of cerebral vessels. SV was calculated with the formula of Broemser-Ranke [4], AP parameters were determined by the method of N. N. Savitskiy [5] and duration of phases of the cardiac cycle was measured by the method of L. B. Andreyev [6] as modified by V. A. Degtyarev [7]. The severity of cardiovascular reactions to LBNP in flight was compared to reactions to ground-based tests, which were considered as the control (see Table).

Changes in hemodynamic parameters of the members of the second main crew aboard Salyut-6 orbital station during LBNP test (-35 mm Hg) before and during flight

Parameter	When recorded	CDR						FLE					
		preflight	flight day					preflight	flight day				
			7	50	85	124	137		7	50	85	124	137
HR/min	Base	65 (60—71)	64	70	77	79	75	57 (55—61)	55	80	70	67	72
	LBNP	78 (74—83)	77	88	98	94	91	66 (63—72)	63	92	86	88	88
AP_d, mm Hg	Base	65 (62—67)	58	60	65	69	69	57 (52—63)	63	60	53	58	64
	LBNP	70 (65—80)	60	63	68	65	70	59 (53—68)	65	68	60	58	58
AP_m, mm Hg	Base	87 (85—90)	83	87	90	89	90	81 (75—87)	90	82	83	82	86
	LBNP	89 (78—102)	81	93	100	100	97	78 (72—92)	80	80	90	83	83
AP_l, mm Hg	Base	101 (97—105)	96	96	99	102	100	98 (93—103)	95	95	99	96	96
	LBNP	98 (85—108)	90	95	109	106	104	93 (82—107)	89	90	96	93	93
AP_e, mm Hg	Base	132 (127—139)	126	133	129	138	138	134 (126—135)	128	147	137	122	133
	LBNP	127 (112—140)	115	125	123	143	125	126 (117—133)	115	120	122	119	120
SV, mℓ	Base	99 (76—111)	98	80	72	68	73	127 (101—133)	95	76	122	84	88
	LBNP	54 (41—68)	48	59	45	55	36	80 (45—102)	57	50	—	—	53
MV, ℓ/min	Base	6.5 (4.9—7.3)	5.7	5.6	5.4	5.3	5.4	7.2 (6.2—7.6)	5.2	6.0	8.5	5.8	6.2
	LBNP	4.0 (2.8—4.8)	3.4	5.1	4.4	5.2	3.3	5.0 (3.2—6.6)	3.6	4.6	—	—	4.5
SPR_a, arbitrary units	Base	27 (23—37)	27	30	32	33	32	23 (21—26)	34	27	19	28	28
	LBNP	40 (30—55)	47	35	40	38	58	32 (22—49)	44	35	—	—	37
SPR_a/SPR_n, %	Base	102 (100—106)	94	102	102	105	105	95 (88—102)	106	96	98	96	102
	LBNP	105 (91—120)	95	109	118	118	114	93 (85—110)	96	98	—	—	100
$PWPV_a$, cm/s	Base	550 (523—571)	675	686	686	823	725	485 (448—514)	561	652	632	740	594
	LBNP	579 (506—623)	810	786	900	778	1174	533 (487—584)	608	702	—	—	820

Note: Range of fluctuations is shown in parentheses.

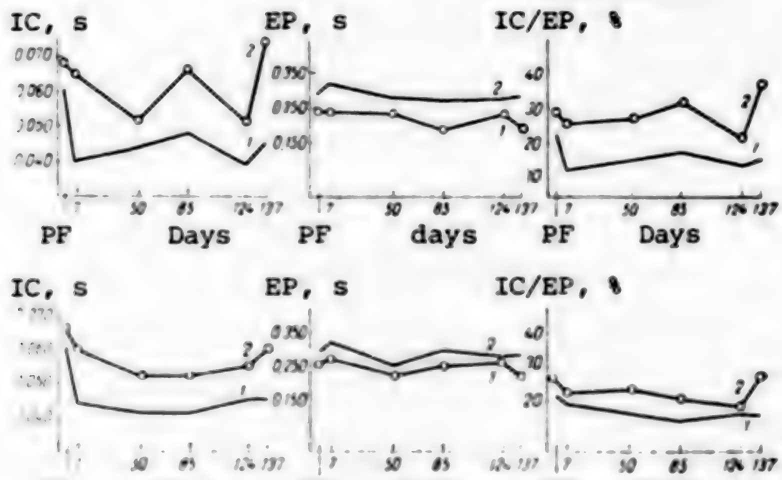
Results and Discussion

None of the LBNP tests performed before and during the flight elicited any discomfort in the cosmonauts. Throughout the flight, both crew members presented intensification of chronoinotropic influences on cardiac function prior to the test. When rarefaction was created in flight, HR increased more than in the preflight tests. In the commander (CDR), HR exceeded preflight values from the 85th flight day on (both in the initial state and during rarefaction). In tests performed on

the 85th, 124th and 137th days, absolute HR with rarefaction reached 91-98/min (relative increment 15-21%). In the preflight tests on the CDR, this parameter constituted 83/min (relative increment 17%). In the flight engineer (FLE), starting on the 50th day of the flight, the maximum HR with rarefaction was in the range of 85-92/min (65-72/min before the flight) and the relative increment was greater (22-31%) during tests on the 85th, 124th and 137th days than before the flight (18%).

On the whole, there was moderate change in AP parameters during LBNP. With the exception of isolated cases (137th day for the FLE), AP_d either failed to change or rose (by a maximum of 8 mm Hg). Along with the usual reaction of AP_p drop (by 7-9 mm Hg), there was also brief elevation (by 4-8 mm Hg) on the 85th day in the CDR and 124th and 137th flight days in the FLE. It is remarkable that, unlike the preflight dynamics, the CDR presented a tendency toward elevation (by 2-10 mm Hg) of AP_1. The decline of circulatory volumes, which usually occurs with LBNP, was never more marked in the tests performed during the flight period than in the preflight period. On the 124th day, with rarefaction of 25 mm Hg, the FLE demonstrated some increase in MV due to increased HR against the background of negligible changes in SV.

The Figure illustrates the dynamics of duration of IC and EP phases, as well as the ratio between them; it shows that in the base state, prior to LBNP, inflight duration of the IC phase was diminished in both cosmonauts (by 16-20 ms), as compared to the level on the ground. At the same time, EP increased only on the 7th day, after which it decreased somewhat or failed to show appreciable change. For this reason, the dynamics of the IC/EP ratio repeated to a considerable degree the changes in the IC phase. Consequently, the base state of cardiac activity in flight differed qualitatively from the preflight state. This was distinctly manifested on the 7th day in the form of the volume load phase syndrome [8].



Dynamics of duration of IC, EP phases and interphase coefficient (IC/EP); %) in LBNP tests before and during flight. PF--preflight.

I, II) CDR and FLE, respectively [Roman numerals not shown in figure]
1, 2) parameters before test and with -35 mm Hg rarefaction, respectively

In subsequent studies, we observed mainly shortening only of the IC phase, which was indicative of formation of a new cardiac functional level. As we know, the

duration of the IC phase is proportional to the gradient of end-diastolic pressure in the aorta and ventricle, and it is inversely proportional to the rate of elevation of intraventricular pressure. The volume of the ventricular cavity, which may be reduced in weightlessness, is one of the decisive factors for intraventricular pressure. Perhpas, this is one of the causes of shortening of the isovolumetric interval. Nor can we rule out the possibility of decline of this pressure gradient as a result of elevation of end-diastolic pressure in the ventricle.

During the LBNP tests, the CDR presented relatively more marked changes in phase parameters, as compared to the base levels, on the 7th, 85th and 137th days (IC longer by 0.025-0.029 s, EP shorter by 0.080-0.085 s, 0.13-0.15 increase in IC/EP). Before the flight, the deviations of these parameters constituted 0.01, 0.04-0.06 s and 0.04-0.07, respectively. However, it should be noted that during the test performed on the 7th flight day, the absolute levels of parameters with rarefaction corresponded to preflight levels and, consequently, LBNP elicited normalization of intracardiac hemodynamics, whereas in the tests made on the 85th and 137th days the relative changes in parameters and the absolute levels they reached were indicative of development of more marked deficiency of cardiac blood volume or the so-called hypodynamia phase syndrome. This was also indicated by the more marked changes in other hemodynamic parameters during these tests.

In the FLE, signs of insufficient load on the heart with blood was manifested more markedly during rarefaction, as compared to ground-based dynamics, only in the test on the 137th day (0.015 s increase in IC, 0.063 s decrease in EP, 0.111 increase in IC/EP ratio, versus 0.01, 0.045 s and 0.07, respectively before the flight). In this test, EP decreased to 0.222 s (versus 0.240 s before the flight). It should be noted that there was more marked extension of the IC phase in all inflight tests on the CDR than on the ground, whereas the changes presented by the FLE in most flight tests did not differ from preflight findings.

In the inflight LBNP tests, we also found that there was more marked increase in PWPVa than before the flight, throughout the mission in the CDR and only at the end thereof in the FLE.

As shown by the rheographic studies, the degree of decline of pulsed filling of cerebral vessels under the influence of LBNP was the same in all inflight tests in both cosmonauts as before the flight. There was prevalence of a constrictive reaction in small vessels. During rarefaction, the absolute values of parameters of arteriolar and venous tonus were close to preflight levels, even when there was more marked hypotonia initially. Perhaps, this was indicative of a greater strain of adaptive and compensatory mechanisms than on earth.

Thus, the inflight studies revealed that the reaction of the circulatory system to LBNP during long-term weightlessness undergoes some changes, manifested by more marked tachycardia, signs of insufficient blood volume load on the heart, increased elastic tension of vascular walls, great vessels and constrictive reaction of fine vessels of the brain.

It is known that LBNP tests on the ground elicit redistribution of blood to the decompression region and deposition thereof in capacitive vessels [9]. This leads to reduction in volume of circulating blood, diminished venous return of blood to the heart and decreased cardiac output [10-12]. Since there is a decrease in circulating blood volume in weightlessness (it is believed by 300-500 mℓ), the

reaction to LBNP in weightlessness must probably develop with greater strain on compensatory mechanisms of the circulatory system. The more marked increase in HR in the inflight tests and manifestation of the phase syndrome of functional hypodynamia can be attributed to development of systemic dehydration, an indirect indication of which is the reduction of body weight and leg volume. The decrease in circulating blood volume under the influence of LBNP could intensify the effect of inadequate blood volume of the heart and reduce significantly filling of the arterial system above the pressurized level. The latter is probably also the cause of the more marked increase in elastoviscous characteristics of the walls of great vessels. The hypothesis that there is an increase in chronoinotropic influences on cardiac function as a result of activation of sympathetic nervous system function could be another explanation for the change in reaction of the cardiovascular system to LBNP during the flight. In this regard, the inconsistency between the significant changes in phase structure of the cardiac cycle and relatively moderate decrease in circulating blood volumes, which were observed in the test made on the 85th day in the CDR and the one performed on the 137th day in the FLE, could be interpreted as the result of heightened sensitivity of mechanoreceptors of cardiac ventricles to the limited influx of blood to the heart.

The change in reaction of cerebral vessels also merits attention. Increased function of the adrenosympathetic system due to increased sensitivity of cerebral tissue to the relative hypoxia that develops during efflux of blood with rarefaction in a caudal direction during the flight, as compared to the preflight period, might be the cause of marked constriction of arteries and veins. The idea has also been voiced that LBNP could elicit greater redistribution of blood in weightlessness, due to increase in blood volume in the thoracic cavity and deconditioning of mechanisms of venous return, than on earth, toward abdominal organs and the lower limbs, which leads to decreased activity of receptors of the cardiopulmonary region and reflex increase in activity of the vasomotor center, with a corresponding intensification of adrenergic influences [14]. One of the important findings of the flight studies is that no overt signs of diminished orthostatic stability were demonstrable as a result of the tests, as a consequence of deconditioning of the cardiovascular system. The relatively moderate AP changes were indicative of absence of symptoms of the vasodepressor effect and retention of the blood vessels' ability to react to vasoconstrictive stimuli.

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SUCCINATE DEHYDROGENASE AND CYTOCHROME OXIDASE ACTIVITY IN TISSUES OF RATS SUBMITTED TO LONG-TERM HYPOKINESIA

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 15, No 6, Nov-Dec 81 (manuscript received 23 Sep 80) pp 69-71

[Article by V. V. Smirnov and P. P. Potapov]

[English abstract from source] The activity of cytochrome oxidase in the liver, skeletal muscles, kidneys, brain and lungs of 56 white rats decreased on days 15 and 60 of the hypokinetic study. The activity of succinate dehydrogenase significantly lowered in the brain and slightly diminished in the lungs and skeletal muscles on the same days. The activity of succinate dehydrogenase in the liver increased on the 90th hypokinetic day.

[Text] The state of redox processes is important to the body's adaptation to hypokinesia. There are data on the activity of various oxidative enzymes under hypokinetic conditions lasting up to 30 days [1-4]. However, most of these data ere obtained by semiquantitative histochemical methods and deal chiefly with hepatic and skeletal muscle tissue. Our objective here was to examine succinate dehydrogenase (SDH) and cytochrome oxidase (CCO) activity in different tissues of rats immobilized for up to 90 days.

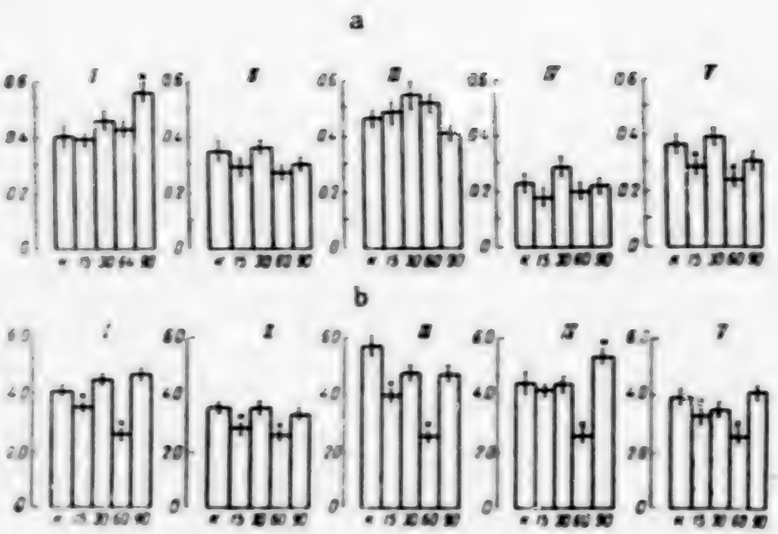
Methods

Experiments were conducted on 56 male white rats (24 of whom served as a control) weighing 180-220 g. To restrict movement, the animals were put in individual small cages made of plexiglas. The control animals were kept in large cages in the same room. All of the rats were fed a proper diet and given water ad lib.

Experimental and control animals were examined on the 15th, 30th, 60th and 90th days of the experiment. We examined tissue of skeletal muscles (from the posterior group of thigh muscles), liver, kidneys, lung (apex of the left lung) and brain (frontal lobe). SDH (EC 1.3.99.1) and CCO (EC 1.9.3.1) activity was measured in tissue homogenates [5, 6]. The animals were decapitated.

Results and Discussion

The weight of hypokinetic animals was 19, 22, 29 and 38% lower on the 15th, 30th, 60th and 90th experimental days than that of control animals, which continued to grow.



SHD (a) and CCO (b) activity in tissues of hypokinetic rats (in mg formasan/g wet tissue/h). X-axis days of hypokinesia.
K—control; x—statistically reliable changes ($P<0.05$). I-V—liver, skeletal muscle, kidney, lung and brain, respectively.

SDH activity in brain tissue decreased by 21.9 and 37.0% ($P<0.05$) on the 15th and 60th days of hypokinesia, respectively. At the same times, there was a tendency toward decline of SDH activity in skeletal muscles and lungs (see Figure, a). On the 30th day, conversely, there was a tendency toward increase in activity of this enzyme in the kidneys and lungs; however, it was statistically unreliable. On the 90th day of restricted movement appreciable changes in SDH activity were demonstrated in liver tissue (it was 37.5% higher; $P<0.05$).

Significant changes were found in CCO activity (see Figure, b). On the 15th day of hypokinesia, statistically reliable decrease in activity of this enzyme was demonstrated in skeletal muscles, liver, kidneys and brain. A decline was found in all examined tissues on the 60th day. Changes were demonstrable only in the lungs (24.1% higher; $P<0.02$) 3 months after the start of the experiment.

It is not deemed possible, on the basis of data available at the present time, to definitively answer the question of the causes of the demonstrated changes. However, our findings and data in the literature [1-4] suggest that, when motor activity is restricted, there is diminished production of reduced forms of coenzymes due to dehydration of substrates as a whole. Under hypokinetic conditions lasting more than 60 days, rats presented an increase in overall gas exchange (scaled to the unit of mass) and increased oxygen uptake by hepatic and skeletal muscle tissue [7]. In view of the fact that CCO activity was diminished on the 60th day of hypokinesia, whereas on the 90th day it was close to control levels in most tissues, it may be assumed that, under these conditions, a significant part of the oxygen taken up by rats is not used for oxidation of reduced coenzymes via the respiratory chain, but for direct oxidation of various substrates by means of diverse oxygenases and hydroxylases.

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LIPID SPECTRUM OF THE MYOCARDIUM OF WHITE RATS EXPOSED TO HYPOXIC HYPOXIA

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 15, No 6, Nov-Dec 81 (manuscript received 17 Nov 80) pp 71-74

[Article by S. A. Sergeyev and G. A. Gribanov]

[English abstract from source] By a modified microthin-layer chromatography the total lipid spectrum of the cardiac muscle of white rats exposed to acute oxygen deficiency in an altitude chamber was investigated. It was found that the content of total lipids, phospholipids, free cholesterol, free fatty acids and triglycerides decreased during acute hypoxia. The exposure induced changes in the amount of glycerophosphatids, phosphatid acids and polyglycerophosphatids whose content diminished significantly. The concentration of phosphatidyl serines and phosphatidyl ethanol amines lowered to a lesser extent while that of sphyngomyelins increased. Acute oxygen deficiency accelerates the release of inorganic phosphate from the heart, thus, together with other factors, leading to disorders in the heart energetics. These findings indicate an important role of hypoxic hypoxia in the disturbances of lipid metabolism of the myocardium. This needs to be taken into consideration in the diagnostics and treatment of such states.

[Text] In recent years, much attention has been devoted to metabolism of the myocardium under ordinary and extreme conditions [1]. It is known that a significant share of energy is furnished to the myocardium by means of oxidation of fatty acids [2]. Yet there are isolated direct studies of the lipid spectrum in different segments of the myocardium in the presence of various physiological and pathological states [3-5]. One of the distinctions of myocardial metabolism is that there is prevalence of aerobic processes, for which reason the study of the effects of hypoxia and ischemia on myocardial metabolism is of paramount importance, particularly as related to the broad exploration of space and significant incidence of ischemic pathology of the heart [6, 7].

Our objective here was to examine the complete lipid spectrum of the white rat myocardium in the presence of acutely developing hypoxia (AH).

Methods

Experiments were conducted in the wintertime on male Wistar white rats. Hypoxia was produced in the experimental group of animals by the pressure chamber method [8]. Pressure in the chamber constituted 190 mm Hg and exposure time was 1 h. The animals were sacrificed by decapitation. We took samples of myocardium from the ventricular region. The samples (70-150 mg) were macerated and homogenized in a buffer solution containing 0.25 M saccharose, 30 mM tris-HCl and 1 mM EDTA, pH 7.4.

The conventional micromethod of Lowry was used to assay water-soluble proteins in an aliquot portion of homogenate and inorganic phosphate was assayed by a modified ultramicromethod with the use of malachite green [9]. The remainder of homogenate was treated with a mixture of chloroform and methanol (2:1) for extraction of total lipids (TL). Nonlipid impurities were removed from the lipid extract by the method of Folch et al. [10]. TL and total phospholipids (TPL) were assayed in the purified lipid extract using previously described methods [11, 12]. Microthin-layer chromatography was used to examine the complete lipid spectrum, as well as qualitative composition and quantitative levels of different lipid fractions [11, 12]. The experimental results were submitted to statistical processing.

Results and Discussion

TL content of the myocardium of rats submitted to acute hypoxia was about one-half the level in control rats (Table 1). There were no qualitative changes in the lipid spectrum. Substantial differences were demonstrated mainly in fractions of free cholesterol (FC) and diglycerides (DG). The relative concentration of the former diminished and that of the latter increased. Analysis of absolute quantities of different lipid fractions of the myocardium in the presence of AH revealed that there was a decrease in most fractions (phospholipids--PL, FC; free fatty acids--FFA; triglycerides--TG; cholesterol esters--CE), but to varying degrees. There was a decrease to one-half or more in quantity of PL, FC, TG and FFA, whereas DG content and certain others remained virtually unchanged. It can be assumed that in the presence of AH there is significant activation of endogenous enzymes that catabolize PL, TG and CE, which disrupts protein-lipid correlations in membranous structures of the myocardium. AH caused some decrease (4.8%, versus 6.3% in the control) in water-soluble proteins of the myocardium. The protein-lipid ratio is 3 in control animals, whereas in rats submitted to hypoxia it increased and reached 4.8, which was also indicative of major disturbances referable to the lipid component of the myocardium. While relative FFA content changed little, the absolute quantity thereof was diminished, which was apparently due to release thereof from diacyl forms of glycerolipids and transport into blood. A comparison of these findings to the results of a study of the effect of hypoxia on blood serum lipid content [13], where an increase in relative FFA content was observed, suggests that the myocardial FFA are one of the sources of increased amount thereof in blood serum in the presence of AH, as a result of significant impairment of myocardial utilization of fatty acids as energy material.

The data pertaining to change in inorganic phosphorus (IP) are rather interesting. Previous studies of blood serum [13] revealed that there is an increase in IP concentration in the blood of animals submitted to AG and, as it was assumed, this is unrelated to breakdown of blood serum PL. In this case, it was shown that the IP content of the myocardium in the presence of AH drops substantially and reliably (from 51.4±6.3 mg% in the control to 32.4±2.4 mg% with hypoxia; $P<0.05$),

and this is quite consistent with the drastic decline in absolute PL content. It is quite likely that part of the IP released upon hydrolysis of several cardiac PL could be the source of blood serum IP.

Table 1.
TL and TL fraction content in myocardium of control white rats and animals submitted to hypoxia (M±m)

Parameter	Relative content %	Absolute content %
TL, % wet weight	1.9±0.3 / 1.0±0.1*	
PL	32,4±2,9 / 31,3±1,5	0,61±0,009 / 0,31±0,001*
FC	13,0±1,3 / 7,3±1,7*	0,25±0,003 / 0,07±0,001*
FFA	15,7±2,2 / 15,7±3,1	0,30±0,006 / 0,16±0,003*
TG	12,6±1,9 / 11,4±0,8	0,24±0,005 / 0,12±0,001*
CE	10,9±1,3 / 10,3±1,4	0,21±0,003 / 0,10±0,001
DG	8,5±1,2 / 14,2±2,9	0,16±0,003 / 0,14±0,002
Methyl esters	6,9±1,2 / 9,8	0,13±0,003 / 0,10

Table 2.
PL and PL fraction content in myocardium of control animals and rats submitted to hypoxia (M±m)

Parameter	Absolute content %	Relative content %
TL	370±62 / 260±58	
GLP	24,8±0.6 / 6,5±0.6*	6,7±1,1 / 2,5±1,0*
Lysophosphatides	19,2±0.6 / 21,4±1,3	5,2±1,0 / 8,2±2,4
PS	35,9±0,9 / 28,1±2,7*	9,7±1,6 / 10,8±4,9
SM	51,5±1,3 / 77,5±4,3*	13,9±2,1 / 2[illegible],8±7,5
PC	77,3±1,4 / 69,9±4,3	20,9±2,4 / 26,9±7,5
PEA	60,7±0,9 / 41,3±1,8*	16,4±1,6 / 15,9±3,2
PA	50,3±0,7 / 15,3±1,1*	13,6±1,2 / 5,9±2,0*
PGP	50,3±0,9 / traces	13,6±1,5 / traces

Note: In both tables, levels for control animals (n = 8) are given in the numerator and hypoxic animals (n = 5) in the denominator; n -- number of experiments; asterisk shows $P<0.05$

Some differences were demonstrated in the study and comparison of phospholipid spectrum of the myocardium of control and hypoxic animals (Table 2). Thus, while there was little change in overall PL content in the myocardium of rats submitted to hypoxia, there was a drastic decline of polyglycerophosphatides (PGP) which, as we know [14-16], are an important component of mitochondrial membranes and activators of a number of respiratory enzymes [16-19]. There was significant decline of relative quantities of other fractions (glycerophosphates--GLP; phosphatidic acids--PA). In view of the fact that these are key components in carbohydrate and lipid metabolism, it is interesting to compare the quantitative changes therein.

In the myocardium of intact rats, the PA and PGP concentration constitutes over one-quarter of all PL. In the presence of AH, the relative concentration thereof decreases to 6%. It should be noted that no marked increase in lysoforms of PL in the myocardium was demonstrated in the presence of AH. It can be assumed that there is substantial activation of phospholipases in the myocardium, with regard to mitochondrial PGP and PA, as well as phosphatase of PA, which hydrolyze them to DG and GLP. GLP, the production of which under these conditions does not require direct expenditure of ATP-type macroergs, could, in turn, be used in anaerobic

glycolytic reactions. Thus, in the myocardium of rats with acute hypoxia, PL (particularly PA and PGP) could become (after a number of preparatory hydrolytic stages) sources of energy in the presence of diminished aerobiosis and shortage of other energy (glucose) sources.

There was also a decrease, but to an insignificant extent, in concentration of other PL (phosphatidyl serines--PS, phosphatidyl ethanolamines--PEA) contained, in the opinion of some authors [20], in the antioxidant systems of the cell. Perhaps, degradation thereof occurs in the form of hydrolysis by phospholipases or peroxidation of unsaturated fatty acids. At the same time, there is significant increase in amount of slowly oxidized PL (sphingomyelins). In view of the existing information to the effect that choline-containing PL in cells, like other representatives, are part of the lipid metabolic system [21], it should be considered that part of the phosphoryl choline released upon hydrolysis of phosphatidyl choline (PC) passes through a number of intermediate products into sphingomyelins (SM). On the basis of conceptions of the importance of interlipid interactions in the function of biological membranes [22], it may be assumed that acute hypoxia alters significantly the structure of the phospholipid spectrum of myocardial membranes and this, in turn, leads to impairment of activity of a number of lipid-dependent redox and other enzymes.

Thus, there is a decrease in TL content of the myocardium, scaled to wet weight, in animals submitted to acute hypoxia. There is also a decrease, but to varying degrees, in absolute levels of virtually all fractions of the lipid spectrum, with the exception of DG. There is the most substantial decrease in concentrations of PL, FC, FFA and TG.

Acute hypoxia elicits changes in amounts of different PL fractions. There is significant decrease in GLP, PA and PGP content. The concentration of PS and PEA diminishes to a lesser extent, whereas the quantity of SM increases.

Acute hypoxia causes release of IP from cardiac tissues, which could lead to serious impairment of energetics of myocardial cells.

The obtained data are indicative of the substantial role of hypoxic hypoxia in disturbances of myocardial lipid metabolism, which must be taken into consideration in diagnostics and therapy of such states.

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STATIONARY MAGNETIC FIELDS AND RETICULAR INFLUENCES ON ADRENERGIC AND CHOLINERGIC SYSTEMS

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 15, No 6, Nov-Dec 81 (manuscript received 22 Oct 80) pp 74-76

[Article by L. D. Klimovskaya and A. F. Maslova]

[English abstract from source] An exposure of rats to a constant magnetic field of 0.4 T for 1 hour caused increases in the blood content of adrenaline, noradrenaline, and acetylcholine, and in the adrenal content of adrenaline. Stimulation of the midbrain reticular formation led to a significant increase of the blood concentration of catecholamines and acetylcholine. After an exposure to the constant magnetic field the stimulatory effects of the reticular formation on the adrenergic systems diminished and on the cholinergic systems remained elevated.

[Text] There is fragmentary information in the literature concerning the effects of high-intensity stationary magnetic fields (SMF) on catecholamine (CA) and acetylcholine (AC) levels in some tissues [1-4]. Such information is sparse; however, it is indicative of change in activity of adrenergic and cholinergic neuromediatory systems under the influence of SMF. We found no data in the literature on levels of CA and AC in the blood of animals exposed to SMF. Our objective here was to examine CA and AC levels in blood and some tissues of rapids exposed to acute high-intensity SMF, as well as to assess the influence of SMF on humoral effects of high-frequency stimulation of the reticular formation of the mesencephalon.

Methods

The studies were conducted on 40 rabbits. Epinephrine (E), norepinephrine (NE) and AC levels were assayed in blood from the marginal auricular vein, adrenals and superior sympathetic cervical ganglion using polarographic analytical methods [5, 6]. Bipolar, nichrome electrodes were implanted in the mesencephalic reticular formation according to stereotactic coordinates. The localization of the tips was checked on histological preparations. Stimulation with square-wave pulses (0.5 ms) at a frequency of 100 pulses/s for 3 min. Procedures involving nociceptive stimulation were performed under urethane anesthesia (1 g/kg in 10% solution, intravenously). The rabbits were submitted to total-body exposure to SMF with induction of 0.4 T for 1 h using an SP-15[a] electromagnet [7]. As a control, experiments of the same duration were conducted.

Results and Discussion

As can be seen in Figure 1, no statistically reliable differences were demonstrable in control experiments between levels of biologically active substances in two samples of blood taken at a 1-h interval while the rabbits were in the experimental situation without use of the electromagnet. Exposure to SMF of 0.4 T for 1 h elicited significant increase in concentrations of E, NE and AC in blood of the same animals. In addition, exposure to SMF led to increase in NE content of the adrenals (see Table). No changes were demonstrated in neuromediator content of the superior cervical sympathetic ganglion. Thus, SMF elicit an increase in release of CA into blood and intensification of E synthesis by the adrenals. It is opportune to recall here that similar findings of increased functional activity of the adrenosympathetic system were made on rats after 1 day in a variable magnetic field with induction of 0.02 T, at a frequency of 50 Hz [8].

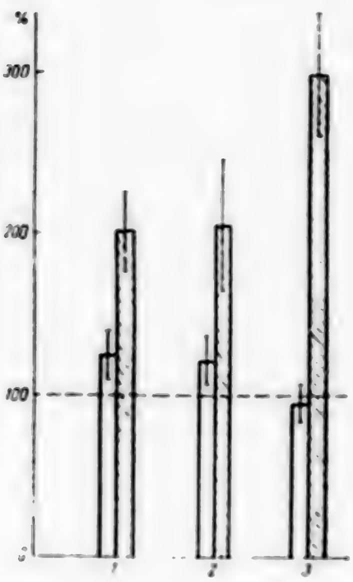

Figure 1.
Effect of experimental situation (white columns) and SMF with induction of 0.4 T (crosshatched columns) on levels of E (1), NE (2) and AC (3) in rabbit blood

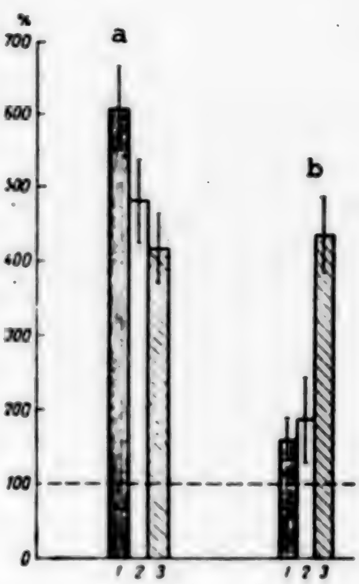

Figure 2.
Effect of stimulation of the reticular formation on levels of E (1), NE (2) and AC (3) in rabbit blood before (a) and after (b) exposure to SMF, 0.4 T

The increase in AC concentration in blood is indicative of involvement of the parasympathetic nervous system also in the reaction to SMF. The coefficient that shows the ratio of blood CA level to AC level (CA/AC) showed virtually no change after exposure to SMF, constituting 102.6±10.8% of the base level. Evidently, under the influence of SMF there is some increase in functional activity of both branches of the autonomic nervous system. Similar humoral changes have been described in the literature, with preservation of equilibrium between adrenergic and cholinergic neuromediators with exposure to a number of factors that do not cause significant impairment of functional state of the organism, for example, moderate physical exercise, Cooke's test on individuals with stable vestibular system and low accelerations [9-11].

Effect of SMF, 0.4 T, on CA and AC levels in blood (in μg/ℓ) and some tissues (in μg/ℓ) of rabbits

Substrate	Experim. conditions	E	NE	AC
Blood	Control	4.45±0.67	4.33±0.72	0.67±0.12
	SMF	7.97±1.44*	6.16±0.90	1.78±0.39*
Adrenal	Control	637.76±111.77	245.66±58.38	—
	SMF	1409.20±134.38*	206.20±56.64	—
Sympathetic ganglion	Control	—	3.06±0.65	3.47±0.92
	SMF	—	2.80±0.37	3.30±0.69

*P<0.05, as compared to the control.

The mesencephalic reticular format-on plays an important part in formation of adaptive and compensatory reactions of the organism that are based on interaction between both branches of the autonomic nervous system and endocrine glands [12]. In view of this, it was interesting to investigate the effect of the reticular formation on CA and AC levels in rabbit blood before and after exposure to SMF. The experimental results revealed that stimulation of the reticular formation elicits marked humoral changes with a stimulus force that is sufficient for development of behavioral reactions of the orienting type (alertness, sniffing, turning the head, circular movements, etc.). As a result of stimulation there was significant increase in concentrations of both CA and AC in blood (Figure 2a). However, there was usually prevalence of adrenergic system reactions and CA/AC increased.

As can be seen in Figure 2, stimulation of the reticular formation elicited a less intensive reaction by adrenergic systems in rabbits submitted to SMF than in control animals. At the same time, the intensity of reaction of cholinergic systems remained at control levels.

Stimulation of the reticular formation after exposure to SMF was delivered against a background of elevated CA level in blood. However, there was decrease not only in relative, but absolute magnitude of reaction of adrenergic structures. Maximum increment of E level in blood constituted 10.10±2.30 μg/ℓ before exposure to SMF and 5.34±2.44 μg/ℓ after.

Thus, in rabbits submitted to SMF there was a substantial decrease in share of adrenergic component in humoral manifestations of excitation of the reticular formation. In this respect, the dynamics of CA/AC changes are graphic. Before exposure to SMF, stimulation of the reticular formation caused it to rise to 309.4±55.3% of the base level and after exposure led to a decline to 46.8±23.6% of the base level.

This conforms to some extent with the results of assessing autonomic functions. Most researchers have observed that SMF leads to prevalence of vagotonic reactions [7, 13]. The obtained data indicate that the changes in functional state of the reticular formation of the mesencephalon play some role in the genesis of humoral and autonomic changes elicited by SMF.

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CLINICAL DISTINCTIONS OF RADIATION SICKNESS WITH EXPOSURE OF DIFFERENT PARTS OF THE HUMAN BODY TO RADIATION

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 15, No 6, Nov-Dec 81 (manuscript received 23 Dec 80) pp 77-80

[Article by G. F. Nevskaya, G. M. Abramova, M. A. Volkova, Ye. V. Pavlycheva, A. S. Skorik and V. V. Yurgov]

[English abstract from source] The clinical picture of radiation sickness of 139 radiological patients exposed to local irradiation of the head, chest and stomach with efficient doses of 210 rad was examined. It was found that at fractionated local irradiations the clinical symptom-complex of radiation sickness was identical to that seen as a result of total-body irradiation. During head irradiation the major symptom was headache and during stomach irradiation nausea. The severity level of radiation damage measured with respect to the clinical symptom-complex as a whole with the aid of the bioinformation model was similar during irradiations of the head and stomach much higher during irradiation of the chest. During head and stomach irradiations the severity level of radiation damage was proportional to the efficient dose. During chest irradiation there was no correlation between the severity level and the exposure to doses of 210 rad.

[Text] It is of both theoretical and practical importance to study radiation reactions when different parts of the body are exposed, particularly for predicting the radiation reactions of the body and developing the means of curbing or preventing development thereof. The works published on this subject are primarily of an experimental nature and referable to the study of biological effects of partial irradiation in doses eliciting a lethal outcome [1-3].

There is no information in the literature concerning man's clinical reactions to irradiation of different parts of the body obtained with equality of absorbed doses. We submit here the results of a clinical study of patients in radiology clinics submitted to divided doses of radiation for a circumscribed neoplastic process localized in different parts of the body.

Methods

The patients were treated using a Luch gamma unit by the standard methods of multifield irradiation used for a specific form of disease. Single doses usually

constituted 200-250 rad per field (2-2.5 J/kg) and cumulative dosage for a course of therapy was 1200-1400 rad (12-14 J/kg). Therapy was administered daily (with the exception of days off) to 2-3 fields 20 to 250 cm^2 in size. The dose fields covered the tumor and surrounding tissues, especially adjacent ones, so that the integral absorbed doses accreted as therapy progressed were sufficient to demonstrate a systemic radiation reaction.

We used the mean tissue effective dose to compare patient reactions under different conditions of delivery of divided doses of local radiation as a gauge of the radiation effects. Median tissue dose of local radiation was determined with the following formula:

$$D = \frac{1}{M} \sum_i D_{0i} d_i S_i y \rho_i , \qquad (1)$$

where M is the patient's body weight (kg), D_{0i} is local radiation dose (in rad, J/kg), d_i is relative depth dose, S_i is area of irradiation field (m^2), y is mean thickness of tissue in the direction of the beam of radiation in the center of the radiation field (m) and ρ_i is the mean density of tissue in the irradiated region (kg/m^3).

Addition was performed according to number of fields irradiated in 1 treatment. D_{0i} constituted 200 and 250 rad (2 and 2.5 J/kg). Relative depth doses d_i as a function of field size S_i (Figure 1) were determined from data in the literature [4]. Mean thickness of tissue in the direction of the radiation beam y was found as the height of a parallelepiped with generating base S_i and height coinciding with the axis of the beam. Since relative doses d_i were obtained in tissue-equivalent material with density ρ_0 = 1000 kg/m^3, we took the effective, rather than geometric value of this height of the parallelepiped for different irradiation fields, i.e., the irradiated volume of tissue with density other than ρ_0 was reduced to a volume with the same generating base S_i and height y. We did not take into consideration the heterogeneity of the body; therefore ρ_i was always considered to equal ρ_0.

Figure 1.
Depth distribution of doses along axis of beam from Luch gamma unit for fields 150 (curve), 80 (circles) and 50 cm^2 (triangles) in size

The calculations revealed that, depending on the size and localization of the irradiation field, the median tissue doses per treatment delivered to the region of the chest, head and abdomen were in the range of 4-8, 10-15 and 15-23 rad (0.04-0.08, 0.1-0.15 and 0.15-0.23 J/kg), respectively.

Since the doses were divided differently for the different variants of therapy, we took into consideration the different nature of recovery processes in analyzing the radiobiological results of such irradiation and used an adequate dosimetric parameter. We selected as this parameter the effective dose, calculated in accordance with the model of Blair-Davidson [5]:

$$\overline{D_{eff} = \alpha \bar{D} + \bar{D}(1-\alpha)e^{-\beta t}}, \tag{2}$$

where α is the magnitude of irreversible damage and β is the recovery constant (in day^{-1}).

Then the effective dose of divided radiation was found to be:

$$\overline{D_{eff} = \sum_j D_{eff}(t_j)}. \tag{3}$$

where summation was performed according to number of treatments j, and t_j is the time that has elapsed from the time of the jth to the last radiation treatment.

Calculations were made for a number of values for parameters α and β recommended for use in these cases [5, 6]. The results of these calculations are listed in Table 1. As can be seen in this table, the correction factor (effective dose) depends little on parameter α and more on parameter β. For subsequent calculations, we selected factors with parameters $\alpha = 0.15$ and $\beta = 0.022$ day^{-1}. These values of parameters had been used previously [6] to calculate effective doses from solar bursts during long-term space flights.

Table 1.
Values of coefficients $K = D_{eff}/D$ for calculation of effective divided doses of radiation

Values of parameters in model of effective dose	Number of divided doses			
	5	10	15	20
$\alpha = 0.15$; $\beta = 0.022$ day^{-1}	0.946	0.889	0.838	0.791
$\alpha = 0.10$; $\beta = 0.022$ " $^{-1}$	0.943	0.883	0.828	0.779
$\alpha = 0.20$; $\beta = 0.022$ " $^{-1}$	0.949	0.896	0.847	0.843
$\alpha = 0.15$; $\beta = 0.035$ " $^{-1}$	0.915	0.833	0.762	0.701
$\alpha = 0.15$; $\beta = 0.017$ " $^{-1}$	0.958	0.913	0.871	0.832
$\alpha = 0.15$; $\beta = 0.014$ " $^{-1}$	0.965	0.927	0.891	0.858

We calculated the median effective tissue doses using the above methods for each patient on any day of therapy. Over the entire course of treatment, the maximum values thereof did not exceed 210 rad (2.1 Gy). We arbitrarily divided the values into 3 ranges of doses: low (up to 70 rad), moderate (71-140 rad) and high (141-210 rad). The maximum dose for each range was accumulated in 6-10 days of treatment, depending on the method used to irradiate the patients.

A comparison of biological effects of treating various parts of the body within the above dose ranges was made according to incidence and severity of various symptoms of the body's systemic radiation reaction.

In addition to analysis of clinical signs of radiation lesion according to different symptoms of radiation sickness, we assessed damage to the body as a whole by means of a bioinformation model, which we had used previously [7-9]. According to this model, the amount of biological information (BI) is a gauge of "orderliness" of the organism. The biological effect of radiation is induced by impairment of established relations and systems of regulation, as a result of which the amount of biological information changes in accordance with the following formula:

$$\Delta h = \frac{1}{N} \sum_{i=1}^{N} l_i (\ln l_i - 1), \tag{4}$$

where N is the number of parameters used to calculate biological information, l_i is relative value of biological parameter, which equals L_i/L_{oi}, L_i is the

value of biological parameter during development of radiation lesion, L_{oi} is the value of the biological parameter before irradiation and Δb is measured in units of biological information (BI).

Formula (4) was used to calculate the change in man's clinical condition after receiving radiation in divided doses. We used as l_i a value of $l_i = 1 - n_i$, where n_i is the observed incidence of the ith symptom.

Results and Discussion

We examined 139 patients who underwent treatment with divided doses of radiation for a circumscribed neoplastic process localized in the region of the head (36 people), chest (68 people) and abdomen (35 people). Radiation was delivered to the head for tumors of the mouth, nasopharynx, maxilla and certain other neoplasms. The chest was usually irradiated for tumors of the lung or mammary glands and the abdomen for tumors of the uterus or ovaries. The patients presented no complaints prior to radiation therapy. In the course of treatment they developed symptoms inherent in radiation lesion caused by total-body irradiation. Table 2 lists the most common symptoms and their incidence as a function of radiation dose.

Table 2. Clinical manifestations of radiation sickness in patients who received different doses of radiation to the head, chest and abdomen

Dose range, rad	Treated region	Incidence of radiation sickness symptoms, %										Integral indicator of change in clinical condition, BI
		Weakness	Headache	Vertigo	Nausea	Vomiting	Diarrhea	Diminished appetite	Change in taste	Sleep disturb.	No symptoms	
To 70	Head	21	34	23	32	1	0	31	15	23	9	0.08
	Chest	28	8	14	17	5	0	8	0	8	21	0.01
	Abdomen	43	17	13	40	10	0	27	3	7	4	0.04
71-140	Head	55	60	15	15	0	0	70	55	10	0	0.1
	Chest	10	10	10	20	0	0	10	0	10	11	0.002
	Abdomen	65	3	17	83	31	3	55	10	3	2	0.11
141-210	Head	50	87	87	25	0	0	88	63	6	0	0.18
	Chest	35	23	23	35	3	0	12	0	12	11	0.02
	Abdomen	60	10	40	80	20	0	60	15	0	2	0.11

In the presence of a single set of symptoms of radiation lesion, the incidence and severity of different symptoms differed with treatment of different parts of the body. Thus, with treatment of the head, the prime symptom was headache. It appeared from the first days of treatment (dosage of up to 70 rad) in one-third of the patients; in the course of subsequent irradiation, there was increase in incidence and severity of symptoms. Upon receiving doses of 140-210 rad, 87% of the patients suffered from severe headache, whereas such an integral indicator as weakness was encountered equally often with treatment of the head and abdomen; with doses exceeding 70 rad, this symptom was observed in half the cases.

The prime symptom with treatment of the abdominal region was nausea. More than half the patients presented this symptom with doses under 70 rad, whereas it was marked in 80% of the cases in the range of 70 to 210 rad.

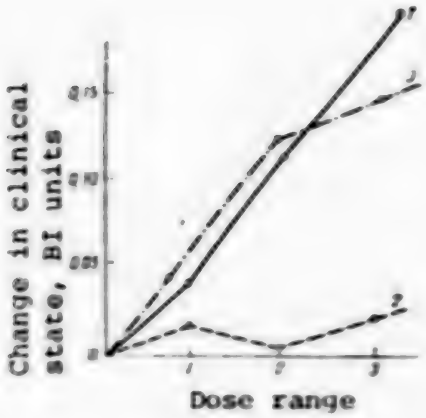

Figure 2.
Change in patients' clinical condition with radiation treatment delivered to the head (1), chest (2) and abdomen (3) in dose ranges of up to 70 rad (1), 71 to 140 rad (2) and 141 to 210 rad (3)

With irradiation of the chest region, clinical manifestations of radiation lesion were considerably less marked, and there was no reaction to radiation in 11% of the patients. There were isolated instances of headache with irradiation of the chest region in doses of up to 140 rad; in the dose range of 140-210 rad, this symptom was encountered in only one-fourth of the patients, being mild in many of them. Even with doses close to 200 rad, weakness developed in only one-third of the patients.

As a result of mathematical processing of clinical data using models of biological information with summation of 10 parameters, it was found that the severity of radiation lesion was the same with treatment of the head and abdomen, and that it was more severe than with treatment of the chest (Figure 2, see Table 2). With delivery of radiation to the head and abdomen, there was a correlation between severity of radiation lesion and level of median tissue effective dose, which was not present with treatment of the chest region.

It is difficult to single out the specific reactions of particular organs and systems falling into the field of irradiation in the overall clinical signs of radiation damage to the body, and at this stage of development of radiobiology it is even impossible. As we see, the symptoms were about the same with radiation treatment of different parts of the body. The differences were only referable to the incidence and severity of different symptoms of radiation reaction. Probably, the greater number of cases with a marked dyspeptic syndrome in the case of treatment delivered to the abdominal region is related to the effect of radiation on the gastrointestinal tract, whereas the higher incidence of such symptoms as vertigo and headache with treatment of the head is attributable to its effect on the central nervous system.

It is imperative to take into consideration the distinctions of clinical manifestations of the body's reaction to radiation when various parts of the body are treated for development of pharmochemical or physical methods of protecting the body against the effects of radiation.

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METHODS

UDC: 612.846:612.886]-087

METHOD OF RECORDING ROTATORY EYE REFLEXES

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 15, No 6, Nov-Dec 81 (manuscript received 8 Apr 81) pp 80-82

[Article by M. M. Levashov and A. V. Dmitriyev]

[Text] The study of vestibular function is closely linked with examination of vestibulooculomotor reactions, among which the so-called rotatory (or trochoid) eye movements, i.e., rotation of the eyes about the anteroposterior axis, are of great interest. Rotatory reflexes in the form of nystagmus occur in response to stimulation of the vertical semicircular canals. A rotatory component is also present in spontaneous vestibular nystagmus and reactions to rotation in the horizontal plane [1, 2]. Stimulation of otolith organs (for example, bending the head to the side) is associated with tonic rotatory reflexes [oculocephalogyric reflexes?].

Unlike other vestibulooculomotor reflexes, the rotatory reflexes cannot be recorded by means of electronystagmography. Motion pictures and photokymography are used for this purpose, which are hardly suitable for routine clinical practice, since they are quite time-consuming and do not yield results directly in the course of an examination.

In developing the method we shall describe here, we tried to meet a number of requirements: visualization of signal on a real time scale, isolation of the rotatory component "in pure form," i.e., impervousness to interference, elimination of the need for calibration with active participation of the subject, adequate sensitivity to record 1° turns, as well as linearity (or close to linearity) of the recorded signal as a function of angle of eye rotation in the range of ±15°.

Let us explain what motivated the above requirements. The importance of obtaining results in real time is obvious. The rotatory reflex occurs quite seldom in "pure form." In the vast majority of cases, the eye performs a complicated movement, during which one movement changes to another, or turns are made simultaneously about two or three axes (vertical and horizontal--anteroposterior and right-left). All other movements play the part of "interference" in relation to the rotatory component, i.e., turning of the eye about its anteroposterior axis. Being recorded they necessarily distort the shape of the sought signal. This is the reason for the requirement of imperviousness to interference. When using electronystagmography, the subject is usually asked to turn the eyes several times at a given angle, which is achieved by changing fixation points, in order to make the calibration. This is how the calibration signal is obtained, to which one can compare

the nystagmogram during quantitative processing. This procedure is unsuitable for studying rotatory nystagmus, since it is impossible to make voluntary eye turns in the frontal plane. For this reason, we had to eliminate the need for calibration with active participation of the subject. Restriction of the subject's head movements in relation to the recording device (for example, camera) inevitably narrows down the capabilities of the examination, which is undesirable if stimulation of the vestibular system is associated with inclination of the head in the sagittal and frontal planes. The requirementsof sensitivity of the method and range of recorded angles are attributable to the previously determined parameters of rotatory nystagmus.

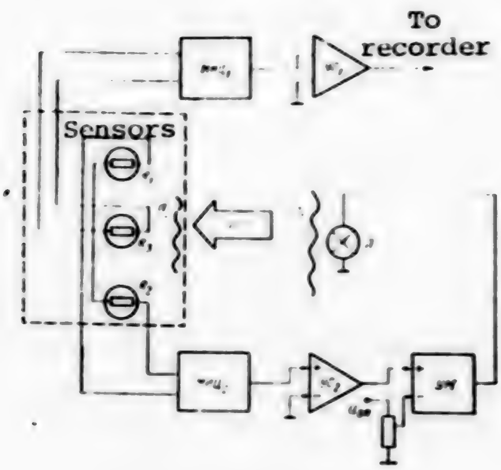

Figure 1.
Diagram of unit for recording rotatory eye movements

The sensor of eye rotation is a photoresistor (R_3) with polarization filter (П_2); photoresistors R_1 and R_2 react to all other eye movements. All sensors (outlined with dash line) are placed on the eyeball. The rest of the elements in the circuit, in the system of coordinates linked to the subject's head, are stationary: light source (Л) with polarization filter П_1, which yields a polarized stream of light (ПСП); bridge measuring circuits (МИЦ_1) and (МИЦ_2); direct current amplifiers (УС_1 and УС_2), as well as direct current amplifier (УМ), whose output signal (filament voltage of light source lamp) is determined by output voltage of amplifier УС_2 and reference voltage $U_{\text{ОП}}$.

The method we developed is based on the use of polarized light. If the beam of light going to the photodetector is passed successively through two polarizers, illumination of the detector will depend on reciprocal orientation of polarization planes. Reciprocal rotation of polarization planes alters illumination proportionally to the cosine of angle of rotation (law of Malus). When the planes are parallel (0° angle), illumination is at a maximum, and when one of the planes is rotated 90° in relation to the other, it is minimal. A miniature photoresistor (R_3, Figure 1) is used as a detector, and it is covered with a polarizing layer. The detector is placed on the anesthetized eyeball with suction cups, after having immobilized the eyelids with strips of tape to prevent blinking. The method for using the eye suction cups has been described in detail by A. L. Yarbus [3]. He also developed a number of parts, among which we used suction device type P_3 to fix the photodetector on the eyeball. The light source and miniaturized amplifier unit were assembled on a mask worn over the subject's head. The signal passes from the amplifier to an automatic recorder, to which are connected a pair of wires from the subject, which do not hamper head movements.

The unit is adjusted prior to examination of eye movements by turning the polarized source already secured on the subject's head. The position of the source remains unchanged during recording, so that only those movements of the polarized detector fixed on the eyeball are recorded that occur in the system of the head's coordinates.

Preliminary reciprocal shifting of polarization planes by an angle of 70° is the best for making records, since in this case the signal as a function of angle of eye rotation in the given range is close to linear (the error factor does not exceed 5% with a ±15° turn), while the sign of the signal depends on the direction of motion (clockwise or counterclockwise). The procedure consists of the following: after placing the suction cup with detector on the eye and securing the mask with source and amplifier on the head, the detector is connected by fine wires to the amplifier input, while the latter is connected to the automatic recorder. The source of polarized light is then turned in relation to the stationary detector until the signal from the detector reaches a minimum, which corresponds to reciprocal shift of polarization planes of the two filters (Π_1 and Π_2, see Figure 1) by 90°; then the angle is reduced to 70° and the test is performed in this position. Calibration signals are recorded twice, before the tests and immediately after them, by turning the source by ±10°. The need for such calibration is attributable to the fact that illumination depends, to some extent, on the distance between the source and eye, and the latter may present individual variations.

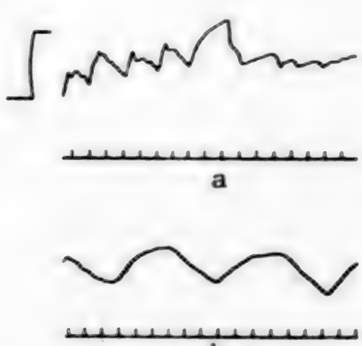

Figure 2.
Segments of tracings of rotatory eye reflexes. Top left—calibration signal ±10°. Time mark—1 s.
a) rotatory nystagmus in man (end of positive angular acceleration, rotation in horizontal plane with head inclined 90° forward)
b) tonic rotation of rabbit eye in response to inclinations in the sagittal plane

We must discuss in more detail the solution of the problem of imperviousness to noise. This technique can assure good recordings of turns in the frontal plane only if the eye does not make any other movements at the same time. Since eyeball movements are almost always complex, turns in the frontal plane will be masked by other movements. Let us imagine that the eye turns in the horizontal plane, as a result of which the light beam does not fall on the detector perpendicularly, but at an acute angle. As this angle decreases, the detector will be illuminated more and more. A signal will be recorded that cannot be distinguished from the one induced by a turn in the frontal plane, i.e., one elicited by increase in angle between polarization planes. In other words, instead of the useful signal (or concurrently with it), interference that cannot be distinguished from it will be recorded.

To rule out the influence of such interference, and additional detector (photoresistors R_1 and R_2, see Figure 1) are put on the suction cup which differs from the main detector in that it has no polarizing covering. The additional detector, which is situated next to the main one, reacts to all eye movements, with the exception of turns in the frontal plane, since the polarization plane is indifferent for it. The signal from the additional detector is used to control brightness of the light source on the principle of negative feedback. In our example, the decreased illumination of the additional detector will immediately and automatically cause a proportional increase in source brightness, and illumination will be restored to the initial level. In all other cases, just as soon as some movement

begins that is different from the rotatory one, at a signal from the additional detector due to change in illumination of the latter, there will be an automatic change in the opposite direction of source brightness, as a result of which there is immediate compensation of the interference and it will not affect the signal from the main detector. In other words, the amount of light reaching the main detector remains unchanged with any movements other than rotatory ones.

Figure 1 illustrates the block diagram of the unit developed to use the described method and Figure 2 illustrates segments of two tracings--nystagmograms of rotatory nystagmus elicited by accelerated rotation on a stand with the subject's head bent 90° forward and tonic rotatory reflexes of a rabbit in response to the animal's periodic inclination in the sagittal plane. Let us recall that in rabbits the orientation of the eyeballs is lateral, i.e., rotatory movements occur in the sagittal, rather than frontal, plane.

This method meets all of the above-formulated requirements, and it can be well-used for recording movements in any plane, i.e., not only rotatory, but horizontal and vertical movements. For example, to record the horizontal component, it is sufficient to place the main and additional photodetectors in the horizontal plane with corresponding change in orientation of the polarized light source. The construction can be described as combining three indetical units: three sets of photodetectors are attached to the same suction cup and oriented in three mutually perpendicular planes, and each corresponds to a separate polarized source, amplifier and recording channel. Concurrent recording of the three signals will furnish a complete picture of all details of a complex eye movement.

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ELECTRODE UNIT FOR TESTING HUMAN H REFLEX

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian Vol 15, No 6, Nov-Dec 81 (manuscript received 13 Feb 81) pp 82-83

[Article by V. I. Zborovskaya and E. A. Skiba]

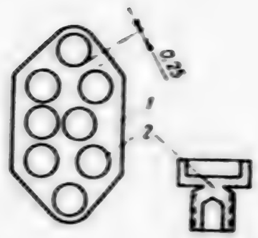
[Text] Use of the method of recording H reflexes makes it possible to test the level of reflex activity of spinal motoneurons at rest and during movement [1-3], as well as to make qualitative and quantitative evalu-tion of various supraspinal and afferent factors [4, 5].

The conventional method of testing the H reflex consists of using square-wave electric pulses to stimulate afferent fibers of a mixed nerve and then recording the evoked bioelectric responses. In the case of recording the H reflex from the soleus or gastrocnemius muscle, stimulation from an active point electrode (cathode) is delivered to the projection region of the tibial nerve on the skin of the popliteal fossa [6-8].

Since there is significant individual variation of localization of the tibial nerve in the region of the popliteal fossa, it is difficult to find the "stimulation point." Moreover, immobilization of the electrode in the popliteal fossa, which is filled with friable cellular tissue, could cause displacement of the electrode. It is known that even insignificant movement of the cathode would alter the nature and magnitude of response signals [9]; for this reason, our objective here was to refine the method and technique for recording the H reflex by increasing the precision of electrostimulation and reducing the time spent on preparing for the tests.

Methods

We developed and constructed an electrode unit for electrostimulation of peripheral nerves or muscles. It has 6 electrodes 8-10 mm in diameter, which are mounted on an elastic dielectric plate. The shortest distance between electrodes is 0.25 mm, which precludes interelectrode short-circuiting and reciprocal influences. The shape and dimensions of the plate (see Figure) were based on the anatomical distinctions of the popliteal fossa. The rounded corners of the plate protect the skin from trauma when the electrode unit is secured firmly. When the electrode unit is placed in the region of the popliteal fossa, there is sufficient coverage of the projection region of the tested nerve.



Schematic rendition of electrode unit for testing human H reflex
1) dielectric plate
2) electrode

The electrode unit is secured firmly to the region of the popliteal fossa, connected to the electrostimulator through a selector which connects the unit electrodes one after the other. The "stimulation point" is determined from the nature and magnitude of responses elicited in the muscle innervated by the stimulated nerve.

As shown by experience, the proposed unit makes it possible to cover the projection, in particular of the tibial nerve, with 2-3 electrodes. The location of the "stimulation point" in the region of the popliteal fossa is objectively checked according to the nature and magnitude of the bioelectric signal from the muscle in response to electrostimulation. It is particularly important to be able to locate the "stimulation point" from a distance when performing tests in a limited space.

The electrode unit proved itself to work well on a centrifuge, preparations for testing on which were made in limited space and time, and the tests were performed by remote control.

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BRIEF REPORTS

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COMPARATIVE ANTIHYPOXIC EFFICACY OF PRESSURE CHAMBER CONDITIONING AND FASTING OF MAN

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[Article by A. Yu. Katkov, Ye. A. Kovalenko, R. N. Chabdarova, G. A. Davydov, S. A. Vtoryy and N. M. Utkina]

[Text] Investigation of man's endurance of rapidly increasing hypobaric hypoxia as related to different modes of motor activity is of great scientific and practical importance, since under such conditions, with extreme rarefaction of the atmosphere in a pressure chamber, not only hypoxic, but decompression disorders can develop [1-5]. We submit here the results of a study of two theoretically possible means of enhancing man's resistance to rapidly increasing hypoxia: pressure chamber conditioning and fasting.

Methods

These studies were conducted with 11 essentially healthy men who were divided into 2 groups. The first group of subjects was submitted to 10-day "pulsed" pressure chamber conditioning by the method of Ye. A. Kovalenko [6]; the second group of subjects spent 14 days on a total fast, without limiting water intake.

We determined endurance of hypoxia in the first group before pressure chamber conditioning and immediately after it, and in the second group before the fast and on the 14th day of food deprivation. The subject was "raised" continuously in the chamber at the rate of 20 m/s at rest, to maximum tolerance of "altitude." The subject was "raised again at the same speed 30 min after "descending" to "earth," but with concurrent performance of exercise on a bicycle ergometer constituting 200 kg-m/min. In both cases, the subject had to report the current "altitude" when so instructed, every 100 m, using the fingers of his right hand: 1 finger--7100 m, 2 fingers--7200 m, 3 fingers--7300 m, 4 fingers--7400 m, 5 fingers--7500, 1 finger again--7600 m, etc, starting at an "altitude" of 7000 m. When the subject was no longer able to perform such a task adequately, the test was discontinued. In the course of the test, we made a continuous recording of oxygen tension in the skin of the left forearm by the polarographic method. At normal barometric pressure, we determined body weight, gas exchange, morphological and gas composition, acid-base equilibrium of capillary blood.

Results and Discussion

Table 1 lists the results of testing the subjects' endurance of rapidly increasing hypoxia. Analysis of the data in Table 1 revealed that pressure chamber conditioning and fasting improved to about the same extent endurance of hypoxia while exercising, increasing the "ceiling" by 500-600 m. However, the increase in resistance to hypoxia at rest was considerably more marked with fasting. While the "altitude ceiling" at rest rose by 600 m under the influence of pressure chamber conditioning, at the end of the fast it rose by 1200 m. With increase in "ceiling" after both chamber conditioning and the fast, we observed a decline of pO_2 level in the skin at the maximum tolerated "altitude" (see Table 1). The antihypoxic effect of pressure chamber conditioning was associated with increase in erythrocytes and hemoglobin of peripheral blood. There was virtually no change in reticulocyte count. During the fast, hemoglobin and erythrocyte content of peripheral blood remained virtually unchanged, while reticulocyte content dropped from 8.8±1.74 to 1.5±0.58%. An analogous reaction of red blood to many days of fasting had been observed previously [7, 8]. All this indicates that stimulation of erythropoiesis is not a mandatory sign of increased resistance to hypoxia. In this case, the antihypoxic effect of pressure chamber conditioning is most likely related to improved delivery of blood to the brain [9].

Table 1. Effect of pressure chamber conditioning and fasting on man's endurance of rapidly increasing hypoxia in chamber and pO_2 of skin

Method of enhancing resistance to hypoxia	Parameter tested	Before enhancing resistance to hypoxia		After enhancing resistance to hypoxia	
		at rest	exercise	at rest	exercise
Conditioning in pressure chamber	Maximum tolerable "altitude" in chamber, m	8800±260	8100±150	9400±140	8600±80
	Skin pO_2, mm Hg:				
	initial	41±1.6	37±1.0	39±1.3	39±1.2
	final	17±1.2	14±2.0	10±0.9	10±0.9
Fasting	Maximum tolerable "altitude" in chamber, m	8800±160	8300±310	10 000±100	8900±190
	Skin pO_2, mm Hg:				
	initial	36±3.0	35±3.7	32±1.0	23±1.9
	final	10±1.9	14±1.8	10±1.3	10±1.5

Note: 1 mm Hg equals 1.33 GPa.

Table 2 shows the nature of changes in some physiological parameters at different stages of the fast. We see from Table 2 that, by the 14th day of the fast, the subjects underwent a so-called acidotic crisis, characterized by normalization of parameters of acid-base equilibrium after temporary metabolic acidosis [10, 11]. During their fast, the subjects presented a marked decrease of gas exchange. On the last day of the fast, prior to "ascent" in the chamber, O_2 uptake was 36% lower than before the fast. The O_2 uptake decreased considerably more than did body weight, which dropped by only 12.5%. This was apparently the chief cause of the high antihypoxic efficacy of fasting.

Table 2. Changes in weight, gas exchange, gas composition and acid-base equilibrium of human capillary blood at different stages of fasting

Parameter	Before fast	Day of fast	
		7	14
Body weight, kg	70.1±2.04	65.1±1.82	31.4±1.94
Minute volume, ℓ/min	6.6±0.58	5.8±1.05	3.7±0.96
O_2 uptake, mℓ/min	279±8.1	236±27.4	178±7.4
CO_2 output, mℓ/min	243±11.5	179±24.7	119±9.0
Capillary blood parameters:			
pO_2, mm Hg	90±2.4	83±4.4	81±7.8
pCO_2, mm Hg	38±1.7	33±1.3	35±2.0
pH	7.41±0.004	7.37±0.011	7.42±0.13
Buffer bases, meq/m	47±0.6	44±0.9	49±0.8
Base shortage, meq/ℓ	0±0.5	−4.8±0.8	−1.0±0.75
Standard bicarbonates, meq/ℓ	24.3±0.48	20.4±0.63	23.6±0.53
True bicarbonates, meq/ℓ	24.0±0.80	19±0.82	22±0.92

Thus, it was established that man's tolerance of rapidly increasing hypoxia can be improved by means of pressure chamber conditioning and, to an even greater extent, under the influence of fasting.

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CONDITION OF MENINGEAL NERVOUS SYSTEM DURING REPEATED EXPOSURE TO TRANSVERSE ACCELERATIONS

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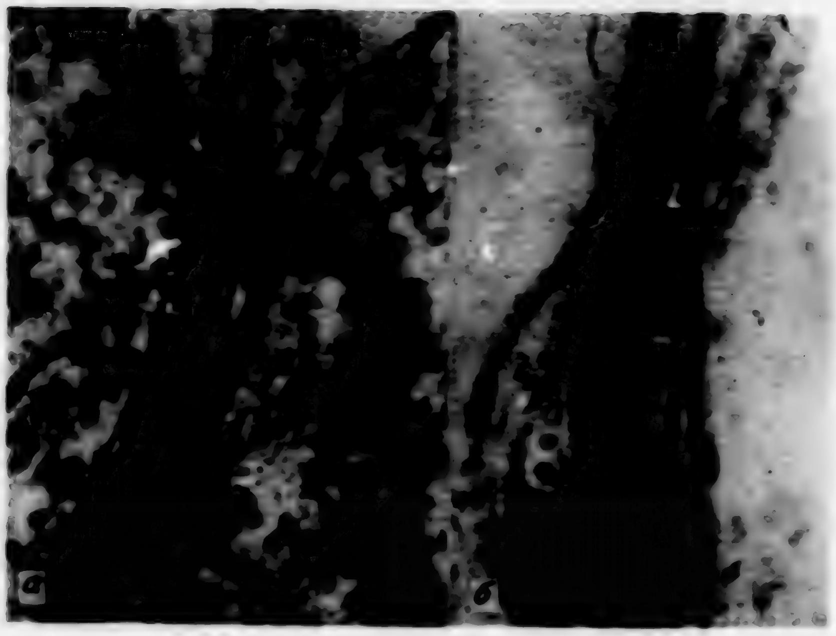
[Article by G. A. Konstantinovskiy]

[Text] There is fragmentary information about morphological changes in the peripheral nervous system (PNS) of the meninges under the influence of accelerations [1, 2]. There is no information about the adaptive properties of the meningeal PNS to repeated exposure (in particular, to transverse accelerations). In view of the fact that the meninges of the brain constitute powerful receptor fields, stimulation of which could have a substantial influence on vasomotor and respiratory reactions [3, 4] and may be the cause of a number of neurological complications, to the extent of severe shock [5, 6], such data are of great interest to comprehensive analysis of the effects of accelerations on the organism.

Methods

The object of our study consisted of the nerve elements of the dura and pia mater of the brain of 19 puberal cats weighing 2-3 kg following repeated exposure to transverse accelerations (chest--back) for 20 min at 24-h intervals, for 6 days. A force of 8 units with a gradient of acceleration build-up and decline of 0.5-0.4 unit/s (calculated by the method described in [7]) was generated on a centrifuge with a 5 m arm, equipped with specially molded containers, in which the animals were immobilized in their physiological position. The cats were sacrificed using ether fumes at different times after the experiments: 1, 3, 7, 30 and 90 days (at least 3 animals per group), which enabled us to track the dynamics of recovery processes. The meninges of five intact animals of the same ages and weight served as a control.

Nervous elements were demonstrated by means of silver nitrate impregnation according to Bielschowsky, in various modifications, followed by gold-plating and additional staining with nuclear-plasma stains. The tigroid substance was stained with thionine according to Nissl. We used the method of Kelbe-Gomori for determination of acetylcholinesterase activity in nerve structures. The myelin sheath of nerve fibers was demonstrated with hematoxylin lacquer according to Spielmeyer and osmic acid according to Schultz. For assay of deposits of calcium salts, some preparations were impregnated with silver nitrate according to Koss.



Swelling and unraveling of nerve fibers in dura (a) and pia (b) mater 3 days after ending the studies. Total preparations. Impregnation according to Bielschowsky-Gross, gold, hematoxylin and eosin stain; objective 40×, ocular 7×

In order to determine the cumulative effects of accelerations on meningeal PNS, we compared the obtained data to the results of previous studies of the effects of single exposure to analogous accelerations [2].

Results and Discussion

There was an increase in reactive proliferations of leptomeninx in the form of "cell spots," "hillocks" and "tufts" [villi] in the superior parts of the fronto-parietal region of the cerebral hemisphere of the animals following multiple exposure to accelerations [8, 11]. Many of these reactive proliferations in animals submitted to repeated accelerations were more innervated than previously observed unrelated to accelerations [8-12].

There was an increase in tortuosity of nerve fibers of the meninges during accelerations, particularly repeated exposure to them.

On the first few days after the experiment (1-3 days), the reactive changes in the meningeal PNS were diffuse and they became particularly marked by the 3d day. In many nerve fibers (mainly myelinated ones), they were manifested by findings interpreted in the literature as "signs of stimulation"--uneven impregnation of

silver, vacuolization, appearance of many varicosities (more than normal, see Figure). The latter were particularly massive along the axons of large nerve fascicles in the pia mater of the brain stem and had no direct relation to its innervation, being merely transitory fibers of the brain's conduction system.

In addition to neural conductors, there were changes in their terminal elements, as manifested by hyperimpregnation, thickening of their preterminal and terminal portions. In the dura, some of them resembled the appearance of small microneuromas.

Swelling, vacuolization of neuroplasm associated sometimes with partial chromatolysis of its basophilic substances were observed in some neurocytes encountered in the meninges. The nuclei of some cells presented an eccentric position.

In addition to signs of irritation, some neural elements presented signs of destruction manifested by fragmentation of nerve fibers, breaks in their terminal terminals and buttons, shriveling of neuroplasm in neurocytes, intensive silver impregnation of neuroplasm and nuclear pyknosis. Such changes were encountered less often with exposure to accelerations only once.

Histochemical analysis revealed that there was appreciable decrease in this period of acetylcholinesterase activity in the meningeal PNS.

Seven days after the experiments, there was a decrease in number of nerve elements presenting marked reactive changes in many regions of the meninges. At the same time, there was some increase in total number of nerve elements destroyed at this period. Evidently, this is related to the fact that in some sites the changes in nerve elements increase and end with destruction thereof.

The reactive changes in the meningeal PNS were more localized 30 days after the experiments. Many nerve elements still presented the above signs of irritation only in the parts of the dura mater covering the frontoparietal regions, central cranial fossae and walls of the cavernous venous sinuses, as well as pia of the brain stem.

In this period, we failed to observe differences in intensity of staining of cholinergic nerve structures, as compared to normal, and this is apparently related to restored acetylcholinesterase activity. On the whole, in this group of animals we encountered less often nerve elements in a state of destruction. The only exceptions were small fields on the external surface of the dura, in the region of the cranial fornix, which underwent severe consolidation and occasionally partial decalcification.

The reactive changes in meningeal nerve elements in the form of signs of irritation and destruction 90 days after the end of the experiments were not more marked than normal [12]. The only exceptions were some small consolidated fields of dura mater and many reactive proliferations of leptomeninx, which had undergone involution by this time, in which some axons in a state of fragmentation were sometimes encountered.

Thus, with the tested accelerations, structural and histochemical changes were demonstrated in the nervous system of the meninges, which were characterized by specific dynamics of development.

The data we obtained, as well as the findings of a number of authors who studied the nerve elements of other organs, offer morphological validation of the conception of onset of "gravity sickness" with exposure to such factors [13, 14]. The nerve elements of different parts of the meninges presented dissimilar reactivity to accelerations, and this must be taken into consideration when making a comprehensive analysis of these factors.

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